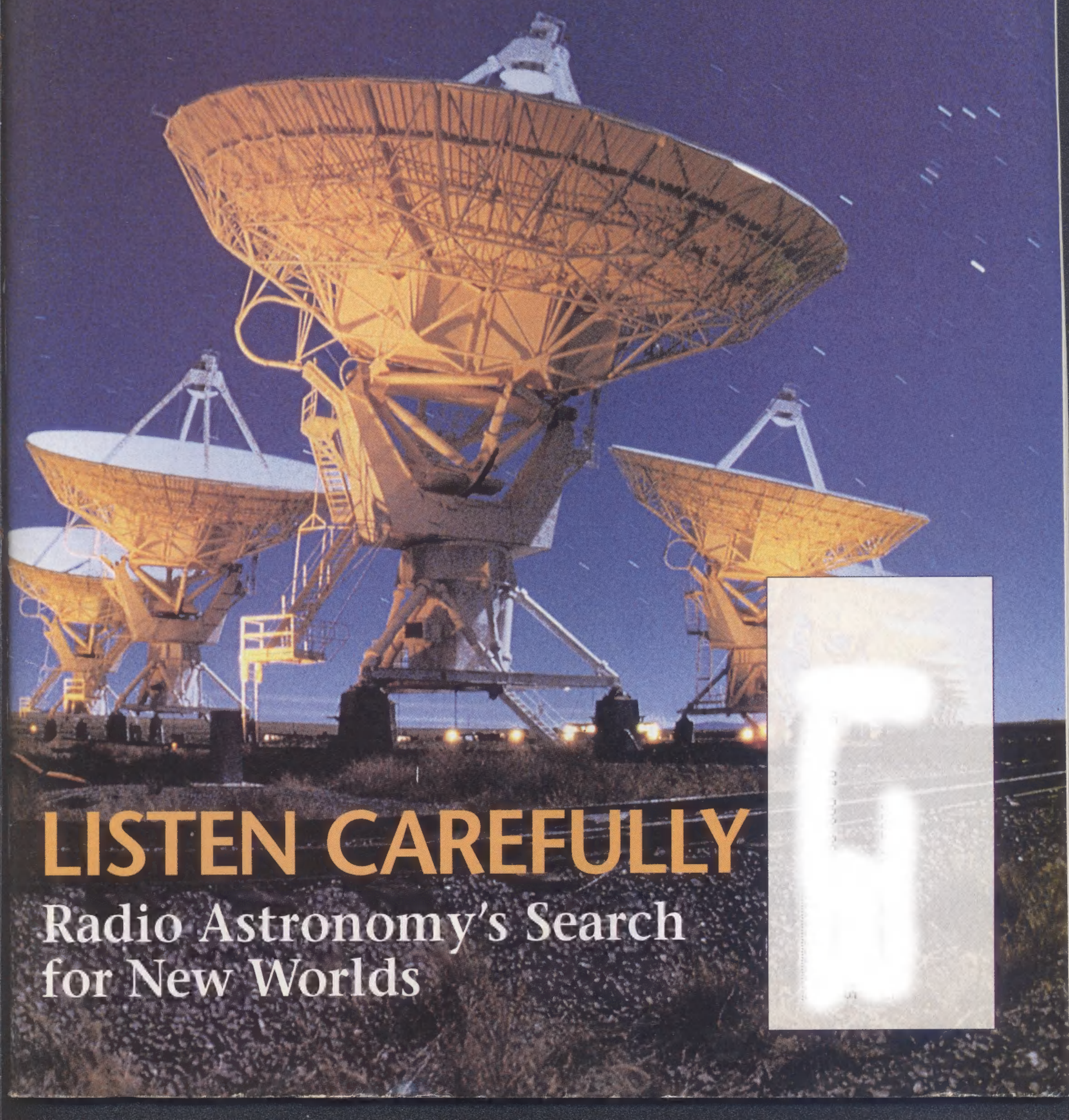
Electronic handcuffs • Up-scale GaAs • Switched multiprocessors

IEEE SPECTRUM

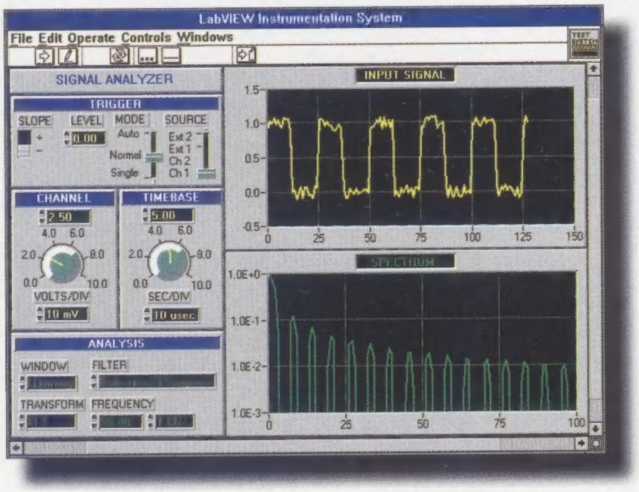
FEBRUARY 1995
THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

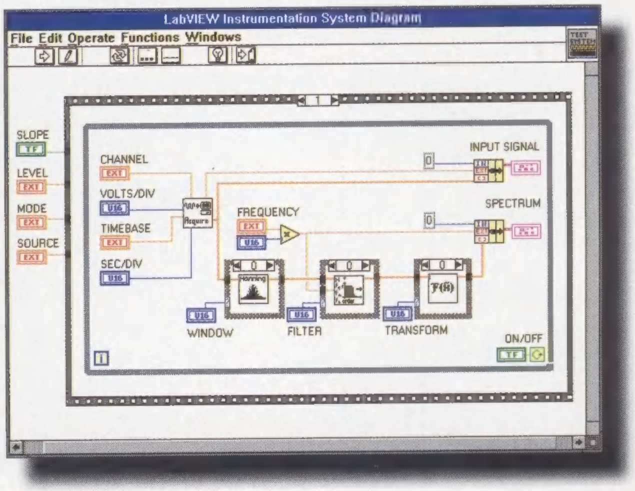


LISTEN CAREFULLY

Radio Astronomy's Search for New Worlds

More than Just Ease of Use ...





True Productivity.

Sure, graphical programming offers ease of use, but the true measure of your success is productivity. For seven years, LabVIEW® has championed graphical programming for instrumentation. And for the thousands of real-world applications like yours, LabVIEW has delivered flexibility, power, and performance to ensure productivity.

LabVIEW®

Flexibility. LabVIEW is a complete language, so you won't spend time working around limitations. You can easily add custom controls to front panels. You can build diagrams with icons for GPIB, VXI, and RS-232 instruments, and plug-in data acquisition boards. You can analyze your data using simple statistics or real-time digital signal processing. And you can even link in compiled C code.

Power. LabVIEW pays big dividends as your programs become more sophisticated. Our patented programming structures keep diagrams manageable. You can modularize, test, and reuse each of your software components. And with the LabVIEW debugging tools, you'll drastically reduce your development time.

Performance. With the compiled performance of LabVIEW, you won't waste time optimizing your program. You'll increase productivity while lowering system cost and raising system throughput.

LabVIEW is not just a pretty user interface and a bunch of icons. LabVIEW delivers the true productivity of an easy-to-use, yet flexible, high-performance graphical programming system.

Call for FREE LabVIEW demo software
(800) 433-3488
(U.S. and Canada)

NATIONAL INSTRUMENTS®
The Software is the Instrument®

6504 Bridge Point Parkway • Austin, TX 78730-5039 • Tel: (512) 794-0100 • 95 (800) 010 0793 (Mexico) • Fax: (512) 794-8411

Branch Offices: Australia 03 879 9422 • Austria 0662 435986 • Belgium 02 757 00 20 • Canada 519 622 9310 • Denmark 45 76 26 00 • Finland 90 527 2321 • France 1 48 65 33 70 • Germany 089 714 50 93 Italy 02 48301892 • Japan 03 3788 1921 • Netherlands 01720 45761 • Norway 32 848400 • Spain 91 640 0085 • Sweden 08 730 49 70 • Switzerland 056 27 00 20 • U.K. 0635 523545

Circle No. 4

newslog

DEC 12. The **Tennessee Valley Authority** said it would not finish three partly built nuclear reactors, two in Scottsboro, Ala., and one in Spring City, Tenn. The plants will stay in mothballs until next year, when the agency will decide whether to scrap them or convert them to another type of fuel. A need to reduce the agency's heavy debt burden was the reason cited for the halt.

DEC 13. Daewoo Electronics of South Korea said it would build its biggest foreign production complex in Pruszkow, Poland. The plant, to be completed next year, will manufacture electronic components, consumer electronic goods, and home appliances.

DEC 13. Teléfonos de Mexico SA, Mexico City, and **Sprint Corp.**, Kansas City, Mo., announced a pact to provide long-distance phone service between Mexico and the United States. The alliance will allow the companies to offer virtually identical service in both countries.

DEC 13. AT&T Corp. said it would link up with **Unisource**, a consortium of Dutch, Spanish, Swedish, and Swiss phone companies, to provide phone services to businesses across Europe. The companies plan to spend US $1 billion on the venture, which is expected to start operating by mid-'95 if it is approved by European regulatory authorities.

DEC 15. Siemens AG, headquartered in Munich, said it would eliminate 12 000 more jobs in 1995—three-fourths of which will be in Germany. The areas most affected will be telecommunications, energy, and computer technology.

DEC 16. Sony Corp., Tokyo, said that it had decided to pit the digital videodisk (DVD) standard it had jointly developed with **Philips Electronics NV** of the Netherlands against that of **Toshiba**, **Time-Warner**, and **Pioneer Electronics**. The Sony-Philips standard has a storage capacity of 3.7 GB of visual data while the Toshiba group's DVD can store up to 10 GB. Sony said its videodisk will use the same size and production technology as the compact disk, lowering production costs, while Toshiba claims its disk will offer better images.

DEC 19. The **National Space Development Agency** of Japan and the **European Space Agency,** Paris, said they had reached an agreement to cooperate in testing the tracking of satellites and optical communications between satellites. The joint effort will use a European telecommunications satellite, scheduled to go into orbit in 1997, and a Japanese satellite, to be launched early the following year.

DEC 19. Toshiba Corp., Tokyo, said it had developed a 500-W excimer laser that emits 5000 pulses per second of ultraviolet laser light. The company said its laser was 17 times faster than commercially available excimer lasers of similarly high power output. The 500 W was attained by improving the high-pressure gas circulation system and using a MOS thyristor as a high-speed switch, rather than the usual vacuum tube switch.

DEC 20. Intel Corp., Santa Clara, Calif., said it would offer customers a free replacement of its flawed Pentium PC chips, which had been found to have a software error. The no-questions-asked offer was an about-face of Intel's previous policy requiring users to justify their need for replacements. Playing down the problem may have backfired after **IBM Corp.**, arguing that Intel had underestimated the potential for errors, said on Dec. 12 that it was halting shipments of computers using Pentium chips.

DEC 21. Tele-Communications Inc., Denver, Colo., said it would pay $125 million for a 20 percent stake in the planned on-line network of **Microsoft Corp.**, Redmond, Wash. Plans call for the service to deliver e-mail, news, and games through cable television wire in 1996.

DEC 23. Ameritech Corp., Chicago, said it had won approval from the **Federal Communications Commission** to build an optical-fiber network and offer interactive video services to 1.3 million homes in five Midwestern states. The company said it would enter into deals with cable programmers and suppliers of home shopping and educational services as well as interactive video games.

DEC 28. Airtel-ASR, the consortium that includes **Air-Touch Communications** in San Francisco and **British Telecommunications**, announced that the Spanish government had awarded the group a license to install a second mobile network in competition with Telefónica, the government-controlled telecom operator. The consortium plans to invest $2.27 billion over the next 10 years.

DEC 28. Power Computing Corp., Milpitas, Calif., said it had signed the first agreement with **Apple Computer Inc.**, Cupertino, Calif., to clone Apple's Macintosh computer. Power Computing said it would start selling the cloned Macs by mail in March and make them available by mid-'95 to other computer makers to sell under their own names.

DEC 29. Alphatec Electronics PLC, Bangkok, Thailand, said it would invest about $1 billion to build a plant to produce 20-cm ultrathin silicon wafers. The company said it had already lined up technology advisers and potential customers like AT&T, Rockwell International, and National Semiconductor.

DEC 29. Unisys Corp., Blue Bell, Pa., said it would cut 4000 jobs—about half in the United States—in 1995. The company blamed the cuts on the continuing shift of its business from mainframes to computer services.

DEC 30. Advanced Micro Devices Inc., Sunnyvale, Calif., said it had won a ruling from the **California Supreme Court** that allows it to keep the profits it made from cloning **Intel Corp.'s** now defunct 386 microprocessor under a cross-licensing agreement. Intel had been trying to win damages that could amount to $1 billion. The companies are still involved in three Federal cases regarding the licensing agreement.

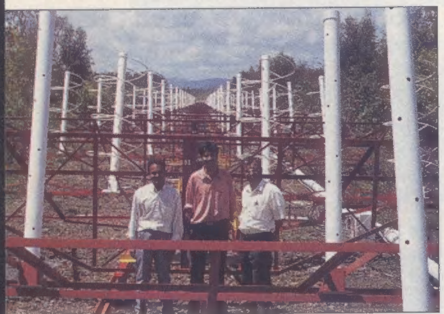
JAN 4. Computer Sciences Corp., Calverton, Md., said it had received a $1.5 billion contract from Hughes Aircraft Co., Los Angeles, to perform its data management functions over the next eight years. The deal calls for about 1100 Hughes employees to transfer to Computer Sciences.

Preview:
FEB 19–25. National Engineers Week will celebrate the theme "Engineers: Turning Ideas into Reality." Thousands of engineers are scheduled to increase public understanding of the profession through school teach-ins, technology fairs in shopping malls, student competitions, and awards programs. For information, call the group's headquarters in Alexandria, Va., at 703-684-2852.

SALLY CAHUR

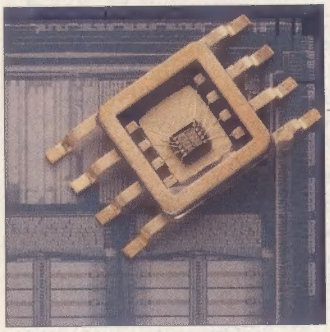
contents

FEBRUARY 1995 VOLUME 32 NUMBER 2



GLENN ZORPETTE

JEFF BARCAN



VITESSE SEMICONDUCTOR CORP.

New Mexico's Very Large Array is helping radio astronomers probe the secrets of the universe (p. 18). Array Cover photography © 1995 Roger Ressmeyer – Starlight

IEEE SPECTRUM (ISSN 0018-9235) is published monthly by The Institute of Electrical and Electronics Engineers, Inc. 345 East 47th St., New York, NY 10017, U.S.A. Canadian Post International Publications Mail (Canadian Distribution) Sales Agreement No. 0338087. Cable address: ITRIPLEE. Telex: 236-411. Fax: 212-705-7453. INTERNET: m.slovick@ieee.org ANNUAL SUBSCRIPTIONS. IEEE Members: $11 included in dues. Nonmembers: $36. Libraries/institutions: $157. SINGLE COPIES. Members: $8 first copy. Nonmembers: $16. MICROFICHE SUBSCRIPTIONS. Members: $16. Nonmembers and libraries: $157. POSTMASTER: Please send address changes to IEEE Spectrum, c/o Coding Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855. Second Class postage paid at New York, NY, and additional mailing offices. Canadian GST #125634188. Printed at 8649 Hacks Cross Rd., Olive Branch, MS 38654, U.S.A. IEEE Spectrum is a member of the Audit Bureau of Circulations, the Magazine Publishers of America, and the Society of National Association Publications.

OPNET MODELER

Precision Modeling of Communications Networks

Light years ahead of other network simulation tools

- advanced X-based user interface
- hierarchical specification
- industry-standard state-transition diagrams
- 300 communications and simulation primitives
- highly efficient simulations
- sophisticated analysis tools
- interactive animations
- application program interface
- floating license system
- library of detailed protocol models including TCP/IP, ATM, X.25, 802.X
- proven track record

MIL 3, Inc.

3400 International Drive, NW
Washington, DC 20008
Tel: 202-364-8390
Fax: 202-364-8554
E-mail: info@mil3.com

 Sales offices in Europe, Asia, Australia, and the Middle East.

Circle No. 17

contents

ELECTRIC POWER RESEARCH INSTITUTE

CINDY CHARLES

KEN HAMILTON

departments

IEEE SPECTRUM

staff

EDITOR and ASSOCIATE PUBLISHER: Murray Slovick
MANAGING EDITOR: Alfred Rosenblatt
SENIOR TECHNICAL EDITOR: Gadi Kaplan
SENIOR EDITORS: Trudy E. Bell, Richard Comerford, Tekla S. Perry, Michael J. Riezenman
SENIOR ASSOCIATE EDITORS: John A. Adam, Glenn Zorpette
ASSOCIATE EDITOR: Linda Geppert
HEADQUARTERS: New York City, 212-705-7555
BUREAUS: WASHINGTON, D.C., John A. Adam, 202-544-3790; SAN FRANCISCO, Tekla S. Perry, 415-328-7570
CORRESPONDENTS: John Blau (Düsseldorf); Chris Brown (Taipei); Peter Gwynne (Belgium); Robert Ingersoll (Bonn); John Mason (Barcelona); Roger Milne (London); Kim Nak-Hieon (Seoul); Roger Schreffler (Tokyo); Bradford Smith (Paris); Axel de Tristan (Rio de Janeiro); Christopher Trump (Toronto)
CHIEF COPY EDITOR: Margaret Eastman
COPY EDITOR: Sally Cahur
EDITORIAL RESEARCHER: Alan Gardner
CONTRIBUTING EDITORS: Robert Braham, Dave Dooling, John R. Hines, Egil Juliussen, Ronald K. Jurgen, Bennett Z. Kobb, Gerry Khermouch, Sue J. Lowe, Kevin Self, Michael F. Wolff
EDITORIAL SUPPORT SERVICES: Rita Holland (Manager)
EDITORIAL ASSISTANTS: Ramona Foster, Desiree Noel
ART DIRECTOR: Mark Montgomery
ASSOCIATE PUBLISHER, OPERATIONS: Fran Zappulla
BUSINESS MANAGER: Robert T. Ross
PRODUCTION: Alan B. Schafer (Director)
ADVERTISING PRODUCTION: Martin Barbieri (Manager)
EDITORIAL PRODUCTION:
Roy Carubia (Editorial Production Manager)
Paul Miller (Electronic Layout Artist)
Morris Khan (Technical Graphic Artist)
ASSOCIATE PUBLISHER: William R. Saunders
ADVERTISING MANAGER; Michael Triunfo
ADMINISTRATIVE ASSISTANT: Christine Demchak
MAIL LIST SALES: Shelly Newman (Manager)
Lizette Graciani
SALES PROMOTION MANAGER : Eric Sonntag
ASSOCIATE PROMOTION MANAGER: Theresa Fitzpatrick
ADMINISTRATIVE ASSISTANT: Nancy T. Hantman
EDITOR EMERITUS: Donald Christiansen
EDITORS BY E-MAIL:

John A. Adam	j.adam@ieee.org
Trudy E. Bell	t.bell@ieee.org
Richard Comerford	r.comerford@ieee.org
Linda Geppert	l.geppert@ieee.org
Gadi Kaplan	g.kaplan@ieee.org
Tekla S. Perry	t.perry@ieee.org
Michael J. Riezenman	m.riezenman@ieee.org
Alfred Rosenblatt	a.rosenblatt@ieee.org
Murray Slovick	m.slovick@ieee.org
Glenn Zorpette	g.zorpette@ieee.org

forum

Engineers can help

Having read Scott Bugno's letter "Engineers for life" concerning volunteer aid agencies [October 1994, p. 4], I note that there is a UK-based group known as "RedR" (Registered Engineers for Disaster Relief). RedR's mandate is to arrange for engineers to travel to the scene of trouble in order to work with other aid agencies. Tasks such as building refugee camps, bridges, drainage and water supply systems, or in the case of the electrical engineer, emergency power generation, telecommunications, and so forth, are all part of RedR's work. Many recent crises (Kurdistan, Somalia, Cambodia, and others) have involved RedR's members.

Membership depends on your capabilities and your availability. It can often involve travel to remote parts of the world at short notice and for long periods. Remuneration is not high, but it usually covers salary to compensate your employer (or yourself if you are self-employed).

More details can be obtained from Jon Lane, RedR, 1–7 Great George St., London, England. Perhaps Bugno can start a U.S. branch.

Gareth Monkman
Regensburg, Germany

Better batteries

Articles on "Appropriate technologies" [October 1994, pp. 32–44] describe photovoltaic devices for use in developing countries.

Europeans are using lead-acid batteries with plates made of a lead-antimony alloy with their equipment. In the 1960s my former power company employer installed lead-calcium batteries in power stations and substations. Earlier this type of battery was developed by the Bell System (AT&T) for its communication system.

Batteries with a lead-calcium alloy require almost no make-up water and have better operating characteristics, and automobile batteries now show this improvement. Including lead-calcium batteries in photovoltaic systems would improve operation.

Allan J. McLennan
Wakefield, Mass.

Costly technologies

Although the articles on photovoltaics [October 1994, pp. 34–44] point to challenges in meeting rural demand for electricity, some facts seem distorted in the authors' enthusiasm for their "product." While it is claimed that PV technology can "avoid the huge expenses of expanding electric grids into rural areas," is this assertion supported by the facts?

Is it honest to peg the costs of grid extension as US $20 000 to $30 000 *per kilometer* when this can be done for less than $4000/km in developing countries? Even in the rural areas of the United States, costs are only a fraction of this, even with high labor costs as compared to those found overseas.

Is it honest to place the costs of fuel to provide electricity to 400 million new consumers at $5 billion to $10 billion, while overlooking *recurring costs of batteries* for photovoltaic systems of $8 billion to $12 billion or more annually for the same consumer base?

If the 400 million consumers are content in the initial stages of electrification with the 100–200 Wh provided each day by a household PV system at a cost of $100 billion (assuming costs *well below* present-day costs), why not build grid extensions more appropriately sized to meet this need? Then the cost will be less than the $100 billion to supply 100 W and up to 2400 Wh each day, rather than the total of $350 billion to $500 billion claimed to supply up to 500 W.

Although photovoltaic technology has appealing attributes and clearly has a role, real obstacles to electrification in rural areas overseas remain to be addressed. Overlooking inconvenient facts does little to help identify these obstacles so that efforts can then be focused on overcoming them.

One could add that, because centrally generated electricity is cheap in comparison to the photovoltaic alternative, a parallel challenge should be to find ways to reduce the cost of transmitting and distributing this power, rather than jumping onto the bandwagon promoting photovoltaics as a substitute (which it is not). Although the technology is useful for minimal lighting and TV use and is in demand by those who can afford it, it cannot make a large impact on rural economic development, without which there is little hope for those in rural areas.

Allen R. Inversin
Riverdale, Md.

Author Erik H. Lysen replies: I hope the following comments may stimulate the debate.

Grid extension costs: the quoted line costs of $20 000 to $30 000/km are typical for a range of developing countries, but of course there are countries where it is cheaper. This is why I quoted Munasinghe's values: $200 to $3650 per rural connection, and obviously PV cannot yet compete with the low end of the scale.

Battery costs: battery costs are part of the recurrent costs of the PV system. With a battery costing $40 to $120, and an average lifetime (for a good battery) of four years, the total costs for the future maximum number of 400 million rural households would be between $4 billion and $12 billion annually, in agreement with Inversin's estimate. It should be noted, though, that these are largely local costs and will generate local jobs, because with this market size most countries will have their own battery-manufacturing and -recycling industry, as is the case with Indonesia, for example. The need to take care of the environmental aspects at an early stage remains urgent, as I mentioned at the end of the article.

Low-power rural grids: installing a centrally powered grid that can distribute only 0.1 to 0.2 kWh per day to each consumer is the nightmare of every power company. I still remember vividly the remark of the chairman of the Andhra Pradesh utility in India, a country where the rural load is still reasonable because of the relatively large pumping load. He said: "Mr. Lysen, for every farmer I do not have to connect, I offer you Rs 10 000 to support the installation of an alternative option."

In other words, with an even lower rural consumption, the financial losses of power companies would be even higher, and this is exactly the strength and beauty of the PV option—for 0.1 to 0.2 kWh a day it is simply the most attractive option in sites at a certain minimum distance from existing grids.

Rural economic development: there is ample evidence, laid down in several studies (also by the World Bank), that rural electrification does not cause rural development. If development takes place, electrification comes in because the money is available to pay for it. Let us not forget that communities sometimes have to pay large sums to get the line into their village, in addition to the individual connection costs. In cases such as in Kenya, photovoltaic systems have spread without any subsidy scheme, among those groups who could afford it and needed the service of light and TV, which the national power company could not provide.

Jumping on the bandwagon: in my view photovoltaic-powered and centrally generated rural electrification can and will coexist. Each country, local authority, or funding

forum

agency should analyze which option is the best for the case in question. I predict that more and more people will decide for themselves to buy a photovoltaic system (that is another beauty of the technology), and it is up to us (donor countries) to create the proper conditions to enable them to do so.

In "Appropriate technologies" [October 1994, p. 34], the author omitted an important factor in defining the title phrase—namely, appropriate technology should foster self-reliance and ought not to create a dependency on foreign expertise and technology. If not, even well-intentioned projects perpetuate what E. F. Schumacher described as "unintentional neocolonialism and hopelessness of the poor."

As an example, in place of using imported photovoltaics and electronic pumps in West Africa, an appropriate technology solution would develop the capability for locally produced mechanical or thermal-powered pumps.

This approach would use local labor to manufacture, install, and maintain the equipment, and create a local distribution system. Inappropriate solutions that rely on Western technology engender a continuing dependence and indebtedness for maintenance, repair, and replacement.

This is clearly a boon for those who wish to market Western technology in developing nations, but it is not in the long-term best interests for those in need of assistance.

Arthur Kobayashi
Pleasanton, Calif.

Unappealing ad

I would like to draw attention to the advertisement for the IEEE Financial Advantage Program on p. 13 of the November 1994 issue, in particular the first sentence: "You forget you're exhausted when you hear the word 'daddy!' "

This sentence might lead one to think that IEEE members: 1) are men, 2) are fathers, 3) get home later than the mother and/or the mother does not work, 4) are not mothers. It may also suggest that for all of us who are not part of those categories, the IEEE program has nothing to offer.

The latter is probably not true, but this type of advertising always gives the impression that some of the membership's needs are not really addressed by the IEEE.

Marie-Jose Montpetit
MMONTPET@SPAR.CA

Counter-advice

I hope that no one takes John Hoschette's advice in "Looking good—whatever happens" [December, pp. 42–44] seriously. There are too many ways that it can backfire.

One piece of advice is to be always asking your supervisor if there is something he would like done that you could do on your own time. There are a number of ways in which this can cause a person problems.

First, you are telling your supervisor that you have a very low opinion of the value of your time. He will value it in the same way by giving you tasks of marginal utility. You will not get credit for these tasks because they have so little value.

Second, when a real crisis surfaces, you may be so bogged down in trivial tasks that your supervisor will turn to someone else. This is known as stereotyping, and it is familiar to any woman who has been asked to get the coffee.

Third, if the failure is really spectacular, you may be asked to participate in a cover-up. This is a lose-lose situation, and the best way to cope is not to get asked. The best way not to get asked is to make it clear well in advance that there are certain things that you will not do.

Hoschette also suggested sending late-night and weekend e-mail to let your boss know you have been working late. He apparently does not realize that this can be faked.

Another of his suggestions was to send your boss a memo every time you have a success. Bozo filters were invented to protect bosses from people like that. Getting caught in the filter means that your boss has decided you are not telling him anything he needs to know. That will put a stop to any career.

Hoschette's advice may have worked in the past, when corporations worried less about competition. I do not think it will work now.

Victor Skowronski
vskowron@geos.rdrc.rpi.edu

Contrast, not color

I feel that the sidebar items in the articles are generally very effective. I enjoy getting additional information that does not fit exactly in the main article.

My problem is the use of dark colors as backgrounds for the sidebar items. Page 30 of the December 1994 issue is an example. My eyesight is not what it used to be, and the reduced contrast made that sidebar difficult to read. The red headline was even harder to read.

Orange backgrounds reduce readability, but are good accents for tables and Defining Terms. Darker backgrounds in sidebars and figures (see pp. 18 and 21) reduce clarity.

Harvey Glickenstein
h.glickenste@genie.geis.com

The January issue of IEEE Spectrum *was the first in our new design format. We solicit comments on the design, as well as on the content, of the magazine.*—Ed.

Just say giga

The recommended way to pronounce the first *g* in *giga*, at the present time, is like the *g* in *giggle*, according to the latest edition of the American National Standard for Metric Practice (ANSI/IEEE Std 268-1992) (Table 8). The previous recommendation (by NBS and ASTM E 380-86) to pronounce it like *j* has been generally ignored by the masses of engineers, so our standards makers have succumbed to popular (mis)usage and changed their recommendation in the interest of reality. Right or wrong, the masses have prevailed.

Is it prudent to flow with the tide? Only up to a point. When dictionaries accept such concoctions as *irregardless*, pronunciations such as *heighth*, and use of the word *infer* to mean *imply*, it is time to stem the tide. Admittedly, not an easy task, but let's not give in easily!

Frank S. Stein
Kokomo, Ind.

Editorial lapses

In "A long road to overnight success" [October 1994, pp. 60–66], Preveen Asthana uses the dreaded word "inch" when referring to disk sizes ("3.5-inch disk" and "5.25-inch disk"). Whatever happened to metric sizes? This is common usage, yet so are mph, horsepower, and gal/mi. Yet those terms are not used for discussing vehicles. What gives?

Al Jaszek
Needham, Mass.

We adhere to metric standards, but make some exceptions. Here, the phrases are still standard industry usage.—Ed.

Corrections

In Fig. 4 on p. 55 of the September 1994 issue, the last condition in Step 1 should have been >22 °C, and the appropriate action in Step 4, "Turn down the heating."

On p. 1 of the November issue, the travel time for the train ride between Hamburg and Berlin should have been 3 hours.

In the caption for Fig. 1 on p. 33 of the December issue, the gear should have been said to be seeing through chaff (strips of aluminum foil that blind radar by reflecting it), which the airplane at left is dropping. —*Ed.*

Readers are invited to comment in this department on material previously published in *IEEE Spectrum,* on the policies and operations of the IEEE, and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. The Editor reserves the right to limit debate on controversial issues. Contact: Forum, *IEEE Spectrum,* 345 E. 47th St., New York, NY 10017, U.S.A.; fax, 212-705-7453. The e-mail (Internet) address is n.hantman@ieee.org. For more information, call 212-705-7305 and ask for the Author's Guide.

Circle No. 5

calendar

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 80055; 908-562-3878; submit conferences for listing to: Ramona Foster, IEEE Spectrum, 345 E. 47th St., New York, NY 10017; 212-705-7305. For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

february

Telecommunications Information Networking Architecture Workshop—TINA '95 (COM, Vic S/COM); Feb. 13–16; Sheraton Towers Hotel, Melbourne, Australia; Laura Kuzmicky, Telecom Australia, Level 36, 242 Exhibition St., Melbourne 3000, Australia; (61+3) 634 4526; fax, (61+3) 632 7416.

International Solid-State Circuits Conference—ISSCC '95 (SSC et al.); Feb. 15–17; San Francisco Marriott; Diane S. Suiters, Courtesy Associates Inc., 655 15th St., N.W., Suite 300, Washington, DC 20005; 202-639-4255; fax, 202-347-6109.

International Topical Symposium on Technologies for Wireless Applications (MTT); Feb. 21–23; Vancouver Trade and Convention Center, British Columbia, Canada; Peter W. Staecker, M/A-Com Inc., 100 Chelmsford St., Lowell, MA 01853-3294; 508-656-2607; fax, 508-656-2777; e-mail, p.staecker@ieee.org.

Second International Conference on Data Transmission—Advances in Data Communications, Technology and Applications (C, IT); Feb. 27–March 1; IEE Savoy Place, Jane Chopping, IEE, DT95 Secretariat, Conference Services, Savoy Place, London, WC2R OBL, London England; (44+71) 344 5477; fax, (44+71) 497 3633.

march

Applied Power Electronics Conference and Exposition—APEC '95 (IA, PEL); March 5–9; Hyatt Regency Hotel, Dallas; Pam Wagner, Courtesy Associates, 655 15th St., N.W., Washington, DC 20005; 202-649-4090; fax, 202-347-6109.

Compcon Spring '95 (C); March 5–9; Stanford Court Hotel, San Francisco; Winfield Wilcke, HAL Computer Systems, 1315 Dell Ave., Campbell, CA 95008; 408-379-7000, ext. 1020; fax, 408-379-5022; e-mail, wilcke@hal.com.

11th International Conference on Data Engineering (C); March 6–10; Grand Hotel, Taipei, Taiwan; R. C. T. Lee, National Tsing Hua University, Hsinchu, 300, Taiwan; (886+35) 735 055; fax, (886+35) 722 713; e-mail, rctlee@nthu.edu.tw.

18th Convention of Electrical and Electronics Engineers (Israel Section); March 7–8; Kear Hamacabiah Hotel, Ramat-Gan, Israel; Ella Eisenberg, Faculty of Engineering, Tel-Aviv University, Tel Aviv 69978, Israel; (972+3) 640 7092; fax, (972+3) 642 3508; e-mail, ella@eng.tau.ac.il.

11th International Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility (EMC, et al.); March 7–9; Swiss Federal Institute of Technology, Zurich; Secretariat, IKT ETH Zentrum, CH-8092, Zurich, Switzerland; (41+1) 256 2788; fax, (41+1) 262 0943.

Southcon '95 (Region 3, Florida C); March 7–9; Greater Fort Lauderdale/Broward County Convention Center, Florida; Joan Carlisle, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045; 800-877-2668; fax, 310-641-5117.

Virtual Reality International Symposium (NN, C); March 11–15; Sheraton Imperial Hotel and Convention Center, Research Triangle Park, N. C.; Jim Cone, 2603 Main St., #690, Irvine, CA 92714; 714-752-8205; fax, 714-752-7444; e-mail, 74710.2266@compuserve.com.

Continued on p. 11

MOVING?

PLEASE NOTIFY US 4 WEEKS IN ADVANCE

Name ______________________ IEEE Member # ______________

Address ______________________________________

City ______________________________________

State/Country ______________________ Zip ______________

- Please print.
- This notice of address change will apply to all publications to which you subscribe.
- List new address above.
- If you have a question about your subscription, please call 1-800-678-IEEE.

ıop on Local and
Area Networks
ı 26–29; Hawk's Cay
rina, Duck Key, Fla.;
3M Corp., Thomas J.
ch Center, Box 704,
ghts, NY 10598;

owards Failure Free,
ctronic Packaging
ch 26–30; Westin Maui,
ii; Avram Bar-Cohen,
Mechanical
University of Minnesota,
, S.E., Minneapolis,
12-626-7244;
398.

mposium on
s Engineering—RE '95
–29; University of
on York, England;
arrison, Department of
ence, University of York,
rk, Y01 5DD,
904) 432732;
32767; e-mail,
Mikrotechnologien, D-09107 Chemnitz, tpierce@basys.dt.navy.mil. math@minster.york.ac.uk.

Post Office
Will Not
Deliver Mail
Without Proper
Postage

IEEE SPECTRUM

IEEE SERVICE CENTER
ATTN: CUSTOMER SERVICE OPERATIONS
445 HOES LANE
PO Box 1331
PISCATAWAY NJ 08855-1331

Conference—ISSCC '95 (SSC et al.); Feb. 15–17; San Francisco Marriott; Diane S. Suiters, Courtesy Associates Inc., 655 15th St., N.W., Suite 300, Washington, DC 20005; 202-639-4255; fax, 202-347-6109.

International Topical Symposium on Technologies for Wireless Applications (MTT); Feb. 21–23; Vancouver Trade and Convention Center, British Columbia, Canada; Peter W. Staecker, M/A-Com Inc., 100 Chelmsford St., Lowell, MA 01853-3294; 508-656-2607; fax, 508-656-2777; e-mail, p.staecker@ieee.org.

Second International Conference on Data Transmission—Advances in Data Communications, Technology and Applications (C, IT); Feb. 27–March 1; IEE Savoy Place, Jane Chopping, IEE, DT95 Secretariat, Conference Services, Savoy Place, London, WC2R OBL, London England; (44+71) 344 5477; fax, (44+71) 497 3633.

march

Applied Power Electronics Conference and Exposition—APEC '95 (IA, PEL); March 5–9; Hyatt Regency Hotel, Dallas; Pam Wagner, Courtesy Associates, 655 15th St., N.W., Washington, DC 20005; 202-649-4090; fax, 202-347-6109.

rctlee@nthu.edu.tw.

18th Convention of Electrical and Electronics Engineers (Israel Section); March 7–8; Kear Hamacabiah Hotel, Ramat-Gan, Israel; Ella Eisenberg, Faculty of Engineering, Tel-Aviv University, Tel Aviv 69978, Israel; (972+3) 640 7092; fax, (972+3) 642 3508; e-mail, ella@eng.tau.ac.il.

11th International Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility (EMC, et al.); March 7–9; Swiss Federal Institute of Technology, Zurich; Secretariat, IKT ETH Zentrum, CH-8092, Zurich, Switzerland; (41+1) 256 2788; fax, (41+1) 262 0943.

Southcon '95 (Region 3, Florida C); March 7–9; Greater Fort Lauderdale/Broward County Convention Center, Florida; Joan Carlisle, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045; 800-877-2668; fax, 310-641-5117.

Virtual Reality International Symposium (NN, C); March 11–15; Sheraton Imperial Hotel and Convention Center, Research Triangle Park, N. C.; Jim Cone, 2603 Main St., #690, Irvine, CA 92714; 714-752-8205; fax, 714-752-7444; e-mail, 74710.2266@compuserve.com.

Continued on p. 11

calendar

Continued from p. 8

Ultrafast Electronics and Optoelectronics Topical Meeting (ED); March 13–17; Dana Point Resort, Dana Point, Calif.; Ellen Murphy, Optical Society, 2010 Massachusetts Ave., N.W., Washington, DC 20036; 202-416-1995; fax, 202-416-6100.

International Conference on Computer Applications in Engineering and Medicine (C); March 15–17; University Place Hotel, Indianapolis, Ind.; Mohamed El-Sharkawy, Department of Electronics Engineering, Purdue University, 723 W. Michigan St., Indianapolis, IN 46202; 317-274-4559; fax, 317-274-4493; e-mail, el-shark@etsun.engr.iupui.edu.

European Workshop on Materials for Advanced Metalization (ED); March 19–22; Park Hotel Hoflobnitz, Radebeul, Germany; Stefan E. Schulz, TU Chemnitz-Zwickau, Zentrum für Mikrotechnologien, D-09107 Chemnitz, Germany; (49+371) 531 3683; fax, (49+371) 531 3131.

National Radio Science Conference (ED); March 21–23; Alexandria University, Egypt; Ibrahim A. Salem, 17 Elqouba St., 3, Roxy Heliopolis, Cairo–11341, Egypt; (20+2) 258 0256; fax, (20+2) 349 8217.

International Conference on Microelectronic Test Structures (ED); March 23–25; New Public Hall, Nara, Japan; Loren W. Linholm, National Institute of Standards and Technology, B-360 Technical Building, Gaithersburg, MD 20899; 301-975-2052; fax, 301-948-4081; e-mail, linholm@sed.eeel.nist.gov.

Signal Processing Workshop (MD/DC Chapter S, NCAC); March 24–25; University of the District of Columbia, Van Ness Campus, Washington; Edgar Neal, 11809 Collins Dr., Germantown, MD 20876; 301-258-8301; fax, 301-258-9163; e-mail, rpierce@oasys.dt.navy.mil.

Seventh Workshop on Local and Metropolitan Area Networks (COM); March 26–29; Hawk's Cay Resort and Marina, Duck Key, Fla.; Yoram Ofek, IBM Corp., Thomas J. Watson Research Center, Box 704, Yorktown Heights, NY 10598; 914-784-6205.

Interpack '95: Towards Failure Free, Low Cost Electronic Packaging (CPMT); March 26–30; Westin Maui, Lahaina, Hawaii; Avram Bar-Cohen, Department of Mechanical Engineering, University of Minnesota, 111 Church St., S.E., Minneapolis, MN 55455; 612-626-7244; fax, 612-624-1398.

International Symposium on Requirements Engineering—RE '95 (C); March 27–29; University of York, Heslington York, England; Michael D. Harrison, Department of Computer Science, University of York, Heslington York, Y01 5DD, England; (44+904) 432732; fax, (44+904) 432767; e-mail, math@minster.york.ac.uk.

books

An intoxicating idea (again)

HANS MORAVEC

World War II incubated two kinds of brain-like machines—analog computers to direct fire at, and bombs from, airplanes, and digital computers to break codes, prepare tables, and simulate atomic explosions. Analog computers acted like small pieces of the nervous system, while digital computers mirrored mental abstractions. After the war the approaches spawned independent academic disciplines explicitly aimed at artificial thought, named cybernetics by Norbert Wiener and artificial intelligence by John McCarthy.

By 1960, two former classmates had become the rival spokesmen for the two approaches. Frank Rosenblatt at Cornell University championed pattern-recognizing electronic nerve nets that were called perceptrons, while Marvin Minsky at the Massachusetts Institute of Technology encouraged students to write thought-simulating programs for digital computers.

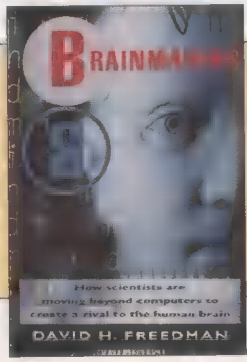
Several years before, Sputnik, with its implicit threat of intercontinental nuclear missiles, struck fear of technological surprise into the U.S. defense community and encouraged it to support far-out research in the universities. Thinking machines were a prime beneficiary, but as funding totals were fixed, there was strenuous competition between research groups.

Already slowing after a hopeful start, research into neural nets ran out of gas altogether with the publication of Minsky's and Seymour Papert's famous work on perceptrons. Their book proved there were fundamental limitations in two-layer nets, and research managers at the Department of Defense were persuaded to divert funding to reasoning programs—notably at Minsky's lab.

Reasoning programs themselves stagnated in the 1970s, after initially encouraging results and inflated promises. Then in 1983, John Hopfield showed how to train three-layer nets, which overcame many perceptron limitations, and by the late '80s neural nets again had funding and a following. Reversing the situation of 20 years earlier, some young enthusiasts declared the reasoning program approach dead. Some reporters believed them.

Author David Freedman, a science reporter, tells a good historical and technical tale. A few errors are confined mostly to the introductory chapter, written after the main text and apparently insufficiently fact-checked. We learn about logic programs and expert systems, as well as perceptrons and the neural net "connectionism" of the '80s. The narrow successes of the many expert systems in business are set against the few applications and many promises of neural nets.

Brainmakers: How scientists are moving beyond computers to create a rival to the human brain.
Freedman, David H., Simon & Schuster, New York, 1994, 214 pp., US $22.



While reasoning programs follow chains of IF-THEN inference rules extracted from tedious interrogation of human experts, neural nets automatically learn to derive imponderable input patterns from examples. In detecting credit card fraud, for example, nets trained on millions of past transactions beat expert systems distilled from the experience of seasoned credit analysts. Echoing the connectionist enthusiasts, Freedman argues that expert systems, and computers in general, are a dead end for machine intelligence, but that nets are up to the job. The book presents Doug Lenat's decade-long "Cyc" effort to encode common sense in as many as 100 million expert-system rules, as the last forlorn hope for reasoning programs.

I was not convinced by Freedman's contention, for reasons evident in my own field of robotics. Many commercial intelligent programs are also to be reckoned with—those for writing and speech recognition, symbolic mathematics, language translation, game playing, industrial vision, and more; they all use pragmatic mixtures of numerical, statistical, inferential, and learning methods that are rarely either expert systems or neural nets.

Expert systems and neural nets are both nonspecific programming techniques for encoding decision criteria and for coming up with input-output relationships. As such, they are often inferior to more problem-specific algorithms for encoding, inference, and learning. In fact, it is highly improbable that future fully intelligent machines will be built with either technique alone, though both may be used in places. Blind biological evolution may be stuck with solutions once chosen, but intelligence-guided technology is not so limited.

Some aspects of the book's overall position are justifiable. Early thinking programs were so small that it was possible to hand-tailor every parameter and decision point. As both computers and problems have grown in size, it has become increasingly necessary and worthwhile to entrust the details to automatic search and learning processes, of all kinds. The degree to which program construction and tuning are delegated to the machine is sure to grow.

The author's strange claim that nets will make computers obsolete, however, suggests an image of soft, lifelike nets versus rigid, mechanical computers. In the '60s, when computers were fabulously expensive, perceptrons were analog devices, but in the '80s connectionists used powerful and relatively cheap digital computers. After all, computers are in one sense universal machines, which can represent any degree of "softness" in fine-resolution numbers.

Most commonly, "nets" are simply matrices of interconnection weights adjusted by a training algorithm. Other many-parameter learning programs have similar structures—hidden Markov models, for instance, and high-degree curve-fitters. The first learn matrices of transition probabilities, and the second tune arrays of coefficients. The few nets implemented as special chips do not contradict this observation: other learning algorithms can likewise be committed to special hardware. The approach rarely pays, however, because in a world of rapidly accelerating universal computers and improving algorithms, speed is a temporary advantage, while an inflexible algorithm is a permanent liability.

Freedman is a young reporter swept away by young researchers intoxicated by a hot idea. No harm done, but things are bound to look differently in daylight, after the party ends and the hangovers subside.

Hans Moravec is a principal research scientist with the Robotics Institute of Carnegie Mellon University in Pittsburgh. He has been developing spatial perception for mobile robots for two decades, and promises practical results by the end of the third. He is author of the forthcoming *Mind Age: Transcendence through Robots* (Bantam, 1995).

GLENN ZORPETTE, Editor

speakout

IN THE STAMPEDE ON CAPITOL HILL TO STREAMLINE AND DOWNSIZE GOVERNMENT, A RARE AND BEAUTIFUL SMALL flower is about to be trampled by thundering hooves. Most of the congressional herd have nothing against flowers, but many members are new and have had little occasion to study congressional botany. Others are so preoccupied with the dust, excitement, and difficulty of keeping their footing that they have little time to think about small flowers.

The Office of Technology Assessment: an endangered species worth saving

M. GRANGER MORGAN

For those unfamiliar with the U.S. Congressional Office of Technology Assessment, or OTA, my comparing it to a precious flower may seem silly hyperbole. But in government, a carefully balanced analysis of complex technical issues is far too rare, and OTA stands as a unique bipartisan source of balanced technical advice for the committees of both the House and the Senate. Indeed, OTA offers a model that has been studied and emulated by national legislatures and parliaments around the world.

Despite these successes, OTA is in trouble. In order to trim a modest US $20 million from the $2 billion budget of the legislative branch, there has been serious talk about eliminating OTA. And even if the agency is left in place, it could be crippled by a massive reduction of its budget to half or even less. Since most of the budget is used to pay the salaries of 200 staffers, lower funds could translate into the firing of many key people.

Doing technology assessment in the politically charged climate of Capitol Hill is no easy task. You cannot reach partisan conclusions and expect to survive. At the same time, you need to produce analysis that helps members make decisions. After some initial fumbling and a few years of groping for the right style, OTA hit its stride about 15 years ago and has been performing superbly ever since.

An OTA report seldom settles a matter; how best to make complex value and policy choices is not a technical question. But OTA frequently manages to frame the problem and spell out the options in a coherent and balanced fashion that supports the subsequent debate. Often these reports work rather like stipulations in a lawsuit. They lay out a basic factual framework that all the parties in the debate agree to share as a starting point. Indeed, it is not uncommon for partisans on opposite sides of an issue to refer to the same OTA report. On complex technical policy issues, nontechnical and semi-technical members and their staffs need such support to identify what the key issues are, so that the political debate may be confined to what is scientifically accurate and technically feasible.

Why is there talk of eliminating or dramatically cutting the agency if it has been so successful? The most important reason involves what social scientists call a "tragedy of the commons." Most members of Congress who know about OTA agree that it does first-rate work. But, faced with a choice between cutting their own staff, and the staff of committees on which they serve, or cutting general support agencies that help all of Congress, most members will look out for themselves. If the resulting congressional decisions are a little less reasoned, or a little less technically realistic, that's tough.

OTA is also at risk because it works mainly for committees, not individual members. Since most committee chairmanships in Congress have just turned over, many new chairmen with little experience of OTA do not yet understand how important and useful it can be. Also, some members of Congress might find it politically advantageous to be able to say they had killed off a whole agency. As one of the smallest agencies around, OTA is particularly vulnerable.

Moreover, despite the fact that OTA has been carefully bipartisan in its activities, some partisan considerations still exist. Ted Kennedy (D-Mass.) played an important role in getting OTA established. And even though Republicans like Alaska's Ted Stevens, Delaware's William Roth, New York's Amory Houghton, and Utah's Orrin Hatch also strongly supported the agency, its identification with the liberal Kennedy in today's conservative climate offers a powerful, if erroneous, political target.

It also does not help that OTA's former, and most successful, director, Jack Gibbons, has gone on to a highly visible position as science adviser in the Clinton White House and that he took several OTA staffers with him when he moved.

Finally, a handful of senators and congressmen, interested in getting the Strategic Defense Initiative program restarted, may remember that OTA was one of the first organizations to raise technical concerns about that project. The fact that those concerns proved justified may not loom large in their current thinking.

Threatening OTA's budget is not just a Republican game. Under a Democrat-controlled Congress, the agency has been level funded in real terms for much of the past decade. In the first few years that this occurred, the agency reduced the impact through such improvements in efficiency as the introduction of modern desktop publishing. But then the budget squeeze really began to hurt. OTA studies that once devoted as much as half their budgets to field work and contracts for small supporting analyses by expert consultants now must devote as much as 80 percent to simply paying staff salaries.

In short, problems in keeping OTA alive and well are not new, but only recently has the agency been put on the endangered list. Unless a big effort is mounted to educate new members of Congress about its value, and to remind old members that careful analyses are essential to making informed decisions about technical matters, OTA could be seriously damaged or destroyed.

Perhaps the best way to understand how OTA works [see "Congress' technical arm: how's it doing?," *IEEE Spectrum*, May 1989, pp. 58–59] is to follow the life cycle of a study. The agency is overseen by a bipartisan joint committee of the two houses of Congress. Called the Technology Assessment Board, the committee must approve all studies, and can also initiate them. More commonly, though, requests come from the chairmen of other committees who pose such questions as, "What should we do about the future of U.S. space launch capabilities?" or "What are the policy implications of the electronic superhighway?" (These questions led to several useful and informative OTA reports.)

These requests rarely show up out of the blue. Senior OTA staffers and senior staff of congressional committees confer on a regular basis, discuss evolving congressional concerns, and explore what areas are most in need of analyses to support future decision-making. Often, several related requests will be woven together into a single study.

In contrast to studies conducted by the National Academy of Sciences complex, OTA studies are done by small teams drawn from a full-time professional staff of about 140. Over half these

people hold Ph.D.s in a variety of fields, including science, engineering, and various areas of social science.

In addition to its core staff, every OTA study has an outside committee of advisers who meet several times during the course of the study. Advisers are drawn widely from the many groups that have knowledge or interests related to the topic at hand. The staff's job is to listen carefully to all the different perspectives and insights the committee brings, and then to weave them into the final report in a balanced way.

While this may sound like a recipe for vanilla-flavored pabulum, in fact it usually yields a spicy, interestingly textured product. OTA reports are lively, comprehensive, and attractively packed. Full reports may range up to a couple hundred pages, but are always accompanied by both a condensed version and a one-page summary.

The reports place great emphasis on accurately simplifying and communicating the key ideas on complex technical topics in words that the semi-technical and non-technical members and their staffs can understand. They are also widely used in the executive branch, in think tanks, and in universities all over the world. OTA uses various methods to balance its treatments while retaining substance. One of the most effective involves the use of IF-THEN clauses: "If Congress wishes to achieve such and such, then it should do so and so."

Engineers are often the most vociferous critics of congressional actions that are at odds with sound science and good technical practice. As such, we have a special obligation to work to preserve a strong and viable OTA. Whatever our individual political persuasions may be, we all believe that the Congress must be well informed when it takes actions that involve technology. A healthy OTA offers one of the best assurances that this will happen. Individually, and as a community, engineers must make it clear to Congress that OTA is one endangered species that should be preserved and nurtured.

M. Granger Morgan (F) is head of the department of engineering and public policy at Carnegie Mellon University in Pittsburgh, where he is also a professor of electrical and computer engineering. His research deals mainly with problems in technology and public policy. He has had many contacts with the Office of Technology Assessment, is a frequent user of its reports, and has served as a member or as chairman of a number of advisory boards for its projects.

calendar

Continued from p. 11

Fourth International Workshop on Responsive Computer Systems (CS); March 29–31; Hotel President, Berlin; Volker Tschammer, GMD-Fokus, Hardenbergplatz 2, D-10623 Berlin, Germany; (49+30) 254 99 226; fax, (49+30) 254 99 202; e-mail, tschammer@fokus.berlin,gmd.d400.de.

april

Southeastcon '95 (Region 3, East NC); April 2–5; Sheraton Imperial Hotel and Convention Center, Research Triangle Park, N.C.; Charles J. Lord, 108 Huntington Circle, Cary, NC 27513; 919-781-8148.

Infocom '95 (C, COM); April 2–6; Park Plaza Hotel, Boston; Celia Desmond, Stentor, Floor 6B, 33 City Center Dr., Mississauga, ON L5B 2N5, Canada; 416-615-6507; fax, 416-615-8421.

International Reliability Physics Symposium (ED); April 3–6; Riviera Hotel, Las Vegas, Nev.; Joseph W. McPherson, Texas Instruments Inc., Box 655012, M/S 385, 13353 Floyd Rd., Dallas, TX 75243; 214-995-2183; fax, 214-995-2932.

Second Topical Symposium on Combined Optical, Microwave, Earth and Atmosphere Sensing (GRS, LEO, MTT); April 3–6; Atlanta Renaissance Hotel, Georgia; Melissa Estrin, IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855; 908-562-3896; fax, 908-562-8434; e-mail, m.estrin@ieee.org.

Joint Railroad Conference (VT); April 4–6; Baltimore Marriott Inner Harbor, Maryland; Richard C. Tansill, De Leuw, Cather & Co., 1133 15th St., N.W., Washington, DC 20005-2701; 202-775-3320; fax, 202-775-3389.

14th Southern Biomedical Engineering Conference (EMB); April 8–9; Holiday Inn Downtown, Shreveport, La.; Debi P. Mukherjee, Department of Orthopaedic Surgery, Louisiana State University Medical Center, 1501 Kings Highway, Shreveport, LA 71130-3932; 318-675-6187; fax, 318-675-6186; e-mail, dumkhe@pop3.lsumc.edu.

28th Annual Simulation Symposium (C); April 9–13; Crescent Hotel, Phoenix, Ariz.; Enrique V. Kortright, Computer Science Department, Nichols State University, Thibodaux, LA 70310; 504-448-4406; fax, 504-448-4927; e-mail, ek@reality.nich.edu.

First Malaysia International Conference on Electromagnetic Compatibility—ICEMC '95 KUL (Malaysia Section); April 11–13; Shangri-La Hotel, Kuala Lumpur; Hussein Ahmad, Universiti Teknologi Malaysia, Fakulti Kejuruteraan Elektrik, Jalan Semarak, 54100 Kuala Lumpur, Malaysia; (60+3) 290 4219; fax, (60+3) 293 4844.

Fourth International Symposium on Database Systems for Advanced Applications (C); April 11–14; National University of Singapore; Chung-Kwong Yuen, Department of IS&CS, National University of Singapore, Lower Kent Ridge 0511, Singapore; (65) 772 2831; fax, (65) 779 4580; e-mail, yuenck@iscs.mus.sg.

Intermag '95 (MAG); April 18–21; Marriott Rivercenter Hotel, San Antonio, Texas; Diane Suiters, Courtesy Associates, 655 15th St., N.W. , Suite 300, Washington, DC 20005; 202-639-5088; fax, 202-347-6109.

Information Theory Workshop on Information Theory, Multiple Access and Queueing (IT); April 19–21; Adam's Mark Hotel, St. Louis, Mo.; Leandros Tassiulas, Polytechnic University, 6 Metrotech Center, Brooklyn, NY 11201; 718-260-3511; fax, 718-260-3074.

Fifth International Workshop on Network and Operating System Support for Digital Audio and Video—Nossdav '95 (COM); April 19–21; New England Center, Durham, N.H.; Thomas D. C. Little, Boston University, College of Engineering, 44 Cummington St., Boston, MA 02215; 617-353-9877; fax, 617-353-6440.

First International Conference on Algorithms and Architectures for Parallel Processing (Queensland, Singapore Section, et al.); April 19–22; Mayfair Crest International Hotel, Brisbane, Australia; C. W. Chan, Department of Electrical and Computer Engineering, University of Queensland, Queensland–4072, Australia; (61+7) 365 3985; fax, (61+7) 365 4999.

International Workshop on Charge-Coupled Devices and Advanced Image Sensors (ED); April 20–22; Dana Point Resort, California; Eric R. Fossum, Jet Propulsion Laboratory, M/A 300-315, 4800 Oak Grove Dr., Pasadena, CA 91109; 818-393-0045; fax, 818-354-3128.

Robotics and Automation (RA); April 22–28; Minneapolis Hilton and Towers, Minnesota; Norman Caplan, National Science Foundation, BES, Room 565, 4201 Wilson Blvd., Arlington, VA 22230; 703-306-1318; fax, 703-306-0312; e-mail, ncaplan@note.nsf.gov.

Instrumentation and Measurement Technology Conference—IMTC '95 (IM, Boston Section); April 24–26; Westin Hotel, Waltham, Mass.; Robert Myers, Conference Coordinator, 3685 Motor Ave., Suite 240, Los Angeles, CA 90034; 310-287-1463; fax, 310-287-1851.

International Computer Performance and Dependability Symposium (C); April 24–26; University of Erlangen–Numberg, Germany; Wolfgang Hohl, Informatik III, University Erlangen–Numberg, Martensstrabe 3, D-91058 Erlangen, Germany; (91+31) 857 010; fax, (91+31) 393 88.

17th International Conference on Software Engineering (C); April 24–28; Westin Hotel, Seattle, Wash.; Dewayne Perry, AT&T Bell Laboratories, 600 Mountain Ave., Murray Hill, NJ 07974; 908-582-2529; fax, 908-582-7550; e-mail, dep@research.att.com.

International Symposium on Circuits and Systems—Iscas '95 (CAS); April 28–May 6; Sheraton Seattle Hotel, Washington; Meeting Management, Iscas '95, 2603 Main St., Suite 690, Irvine, CA 92714; 800-321-6338; fax, 714-752-7444.

Rural Electric Power Conference (IA); April 30–May 2; Sheraton Music City Hotel, Nashville, Tenn.; Gregory P. Woodsmall, Northern Virginia Electric Cooperative, 5399 Wellington Rd., Box 310, Gainesville, VA 22065; 703-754-6700; fax, 703-754-6777.

13th VLSI Test Symposium (C); April 30–May 3; Princeton Marriott Hotel, Princeton, N.J.; Prab Varma, CrossCheck Technology, 2833 Junction Ave., Suite 100, San Jose, CA 95134; 408-432-9200; fax, 408-432-0907; e-mail, prab@crosscheck.com.

calendar

may

International Symposium on Electronics and the Environment (TAB); May 1–3; Hyatt Regency, Orlando, Fla.; Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3878; fax, 908-981-1769; e-mail, conferenceregistrar@ieee.org.

Custom Integrated Circuits Conference—CICC '95 (ED, SSC); May 1–4; Westin Hotel, Santa Clara, Calif.; Melissa Widerkehr, Widerkehr and Associates, Suite 610, 1545 18th St., N.W., Washington, DC 20036; 202-986-2166; fax, 202-986-1139.

Fourth International Symposium on Integrated Network Management—Isinm '95 (COM); May 1–5; Red Lion Hotel, Santa Barbara, Calif.; Mary Olson, Isinm '95, Box 22605, Santa Barbara, CA 93101; 805-569-1222; fax, 805-569-2227; e-mail, isinm@cs.ucsb.edu.

International Radar Conference (AES, NCAC); May 7–11; Radisson Mark Plaza Hotel, Alexandria, Va.; Tom Fagan, IEEE International Radar Conference, 1000 Wilson Blvd., 30th Floor, Arlington, VA 22209; 703-247-2988; fax, 703-276-9706.

Second International Test Synthesis Workshop (C); May 8–10; Red Lion Resort, Santa Barbara, Calif.; Ben Bennetts, Synopsys, 700 East Middlefield Rd., Mountain View, CA 94043; 415-694-4244; fax, 415-694-4128.; e-mail, benb@synopsys.com.

Industrial and Commercial Power System Conference (IA); May 8–11; Menger Hotel, San Antonio, Texas; Michael Osborn, 13622 Stoney Hill, San Antonio, TX 78231-1823; 210-671-2853.

International Conference on Acoustics, Speech and Signal Processing (SP); May 8–12; Westin Hotel, Detroit, Mich.; Al Hero, Department of EECS, 4229 Engineering 1, University of Michigan, Ann Arbor, MI 48109-2122; 313-763-0564; fax, 313-763-1503; e-mail, hero@dip.eecs.umigh.edu.

Intelligent Networks Workshop—IN '95 (COM); May 9–11; Ottawa Congress Center, Canada; Javan

Erfanian, Stantor, Floor 6B, 33 City Center Dr., Mississauga, ON, L5B 2N5, Canada; 905-615-6486; fax, 905-615-8421; e-mail, javan@comm.toronto.edu.

Power Industry Computer Applications Conference (PE); May 9–12; Salt Palace Convention Center, Salt Lake City, Utah; R. Chisholm, PacifiCorp. Power Supply, 168 N. 1950 West, Salt Lake City, UT 84115; 801-220-2109; fax, 801-220-4895.

Seventh International Conference on Indium Phosphide and Related Materials (LEOS, EDS); May 9–13; Hokkaido University Conference Hall, Sapporo, Japan; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3893; fax, 908-562-8434.

Microwave and Millimeter-Wave Monolithic Circuits Symposium (ED); May 15–16; Orange County Convention/Civic Center, Orlando, Fla.; Val Peterson, Hewlett-Packard Co., 1412 Fountaingrove Parkway, Building 1, Santa Rosa, CA 95403; 707-577-2304; fax, 707-577-4090.

International Microwave Symposium—MTT '95 (MTT); May 15–19; Orange County Convention Center, Orlando, Fla.; G. K. Huddleston, 506 Lisa Lane, Maitland, FL 32751; 407-339-0336; fax, 407-356-7201.

University/Government/Industry Microelectronics Symposium (ED); May 16–18; J. J. Pickle Research Center, University of Texas, Austin; Mahboob Khan, Advanced Micro Devices, MS 178, Building 965, Thompson Place, Box 3453, Sunnyvale, CA 94088; 408-749-4213; fax, 408-749-5585.

National Telesystems Conference—NTC '95 (AES, MTT, Orlando Section); May 17–19; Orange County Convention Center, Orlando, Fla.; NTC '95, c/o LRW Associates, 1218 Balfour Dr., Arnold, MD 21012; 410-647-1591; fax, 410-647-5136.

Pacific Rim Conference on Communications, Computers, Visualization and Signal Processing (Victoria C); May 17–19; Victoria Conference Centre, British Columbia; Mary O'Rourke, Conference Services, University of Victoria, Victoria, BC V8W 2Y2, Canada; 604-721-84656.

Third ACM Symposium on Solid Modeling and Applications (C); May 17–19; Red Lion Hotel, Salt Lake City, Utah; Mike Pratt, NIST, Building 220, Room A127, Gaithersburg, MD 20899-0001; 301-975-3951; fax, 301-258-9749; e-mail, pratt@cme.nist.gov.

Ninth Conference on Real-Time Computer Applications in Nuclear, Particle and Plasma Physics (NPS); May 21–25; Kellogg Center, East Lansing, Mich.; Ron Fox, NSCL, Michigan State University, East Lansing, MI 48824-1321; 517-353-1678; fax, 517-353-5967; e-mail, fox@rscl.mscl.mcu.edu.

Lasers and Electro-Optics and Quantum Electronics and Laser Science Conference—CLEO/QELS

Continued on p. 14E6

calendar

Continued from p.14E4

(LEOS); May 21–26; Baltimore Convention Center, Maryland; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3893; fax, 908-562-8434.

21st Annual Northeast Bioengineering Conference (EMB); May 22–23; College of the Atlantic, Bar Harbor, ME; Seth Wolpert, 5708 Barrows Hall, University of Maine, Orono, ME 04469-5708; 207-581-2234; fax, 207-581-2220; e-mail, wolpcit@maine.maine.edu.

45th Electronic Components and Technology Conference—ECTC '95 (CMPT); May 22–24; Caesars Palace, Las Vegas, Nev.; Peter J. Walsh, Electronic Industries Association, 2001 Pennsylvania Ave., N.W., Washington, DC 20006; 202-457-4932.

Fifth Dual-Use Technologies and Applications Conference (Mohawk Valley Section); May 22–25; State University of New York at Utica/Rome; Dawn Farry, SUNY IOT at Utica Rome, Box 3050 College Relations Office, Utica, NY 13504-3050; 315-792-7113; fax, 315-792-7222; e-mail, dawn_farry@barney.info.sunyit.edu.

Industrial Automation and Control (IA); May 22–27; National Taipei Institute of Technology, Taiwan; Paul I-Hai Lin, IU-Purdue University, 2101 Coliseum Boulevard East, Fort Wayne, IN 46805; 219-481-6339; fax, 219-485-4269; e-mail, lin@smtplink.ipfw.indiana.edu.

International Conference on Robotics and Automation (RA); May 22–27; Nagoya Congress Center, Nagoya, Japan; Toshio Fukuda, Department of Mechano-Informatics and Systems, Nagoya University, Furo-cho, Chikusa-Ku, Nagoya 464-01, Japan; (81+52) 781 5111, ext. 4478.

International Symposium on Power Semiconductor Devices and Integrated Circuits (ED); May 23–25; Yokohama Convention Center, Japan; Toshiaki Yachi, Nippon Telegraph & Telephone Corp., NTT Interdisciplinary Research Laboratory, 9-11, Midori-Cho, Musashino-shi, Tokyo 180, Japan; (81+422) 59 3129; fax, (81+422) 59 2172.

International Symposium on Electron, Ion and Photon Beams Symposium (ED); May 30–June 2; Scottsdale Conference Resort, Arizona; John N. Randall, Texas Instruments Inc., 13588 N. Central Expressway, MS 134, Dallas, TX 75243; 214-995-2723; fax, 214-995-2836.

International Frequency Control Symposium (UFFC); May 31–June 2; Fairmont Hotel, San Francisco; Michael R. Mirarchi, Synergistic Management Inc., 3100 Route 138, Wall Township, NJ 07719; 908-280-2024; fax, 908-681-9314.

International Symposium on VLSI Technology, Systems and Applications (C, ED, et al.): May 31–June 2; Hyatt Hotel, Taipei, Taiwan; Genda J. Hu, Cypress Semiconductor, MS/1-1, 3901 N. First St., San Jose, CA 95134; 408-943-4861; fax, 408-943-2118.

june

Holm Conference on Electrical Contacts (CPMT); June 4–11; Radisson Governeurs Hotel, Montreal; Holm Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3895; fax, 908-562-1571; e-mail, e.hager@ieee.org.

37th Cement Industry Technical Conference (IA); June 5–8; Caribe Hilton Resort and Casino, San Juan, Puerto Rico; Jose A. Alustiza, Puerto Rican Cement Co., Box 364487, San Juan, PR 00936-4487; 809-783-3000; fax, 809-781-8850.

Eighth International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems (C); June 5–9; Hilton on the Park, Melbourne, Australia; Moonis Ali, Department of CS, Southwest Texas State University, San Marcos, TX 78666-4616; 512-245-3409; fax, 512-245-8750; e-mail, ma04@academia.swt.edu.

Symposium on VLSI Technology (ED); June 6–8; Kyoto Grand Hotel, Japan; Hiroyoshi Komiya, ULSI Laboratories, Mitsubishi Electric, 4-1 Mizuhara, Itam-ishi, Hyogo 664, Japan; (81+727) 82 5131; fax, (81+727) 80 2685.

International Conference on Consumer Electronics—ICCE (CE); June 7–9; Westin Hotel O'Hare, Rosemont, Ill.; Diane D. Williams, 67

Continued on p. 66E1

Get 3 Books for only $9.95

plus 1 book FREE upon prepayment

when you join the

Electronics Engineers' Book Club

YES! Rush me the following titles, billing me just $9.95 (plus shipping/handling [redacted] sales tax). Enroll me as a member of the **Electronics Engineers' Book Club®** according to the terms outlined in this ad. If not satisfied, I may return the books within 10 days for [redacted] full refund and my membership will be cancelled. I agree to purchase just [redacted] more selections [redacted] regular Club prices during the next [redacted] years and may resign anytime thereafter.

Code #'s of my books for $9.95

If you select a book that counts as 2 choices, write [redacted] book number in one box and XX in the next. If you select [redacted] Counts [redacted] 3 choice, write the book number in one box [redacted] XXX in the next [redacted] boxes.

☐ Bill me (FREE book not available with this payment option.)

SPECIAL OFFER: **Prepay your order by check, money order, or credit card and receive a 4th book of your choice FREE.**

☐ YES! I want the FREE BOOK indicated below. My introductory payment of $9.95 plus $9.95 shipping/handling• and applicable sales tax is enclosed.

SINGLE SELECTION ONLY

☐ Check or money order enclosed made payable to: McGraw-Hill, Inc.

Please charge my:

☐ VISA ☐ MasterCard ☐ American Express ☐ Discover

Acct. No. ____________ Exp. Date ________

Signature ____________________

(required [redacted] all credit card orders)

Name ____________________

Address/Apt.# ____________________

City/State/Zip ____________ Phone ________

[redacted] valid for new members only, subject to acceptance by EEBC. U.S. orders are shipped 4th Class [redacted] Post. Canada *must* remit in U.S. funds drawn on U.S. banks. •Canadian orders [redacted] shipped International Book Post—add $12.50 shipping/handling. Applicants outside the U.S. [redacted] Canada will receive special ordering instructions. [redacted] shipping/handling charge [redacted] sales tax will [redacted] to all orders. ©1995 EEBC IEEE295

Get 3 Books for only $9.95

plus 1 book FREE upon prepayment

when you join the

Electronics Engineers' Book Club

YES! Rush [redacted] the following titles, billing me just $9.95 (plus shipping/handling [redacted] sales tax). Enroll me [redacted] member of the **Electronics Engineers' Book Club®** according to the terms outlined in this ad. If not satisfied, I may return the books within 10 days for a full refund and my membership will [redacted] cancelled. I agree [redacted] purchase just [redacted] more selections at regular Club prices during the next 2 years and may resign anytime thereafter.

Code #'s of my books for [redacted]

If you select [redacted] book [redacted] counts as 2 choices, write [redacted] book number in [redacted] box and XX in the next. [redacted] you select a Counts [redacted] 3 choice, write the book number in [redacted] box and XXX in the next [redacted] boxes.

☐ Bill [redacted] (FREE book not available with this payment option.)

SPECIAL OFFER: **Prepay your order by check, money order, or credit card and receive a 4th book of your choice FREE.**

☐ YES! I want the FREE BOOK indicated below. My introductory payment of $9.95 plus $9.95 shipping/handling• and applicable sales tax is enclosed.

SINGLE SELECTION ONLY

☐ Check or money order enclosed made payable to: McGraw-Hill, Inc.

Please charge my:

☐ VISA ☐ MasterCard ☐ American Express ☐ Discover

Acct. No. ____________ Exp. Date ________

Signature ____________________

(required on [redacted] credit card orders)

Name ____________________

Address/Apt.# ____________________

City/State/Zip ____________ Phone ________

Offer valid for new members only, subject to acceptance by EEBC. U.S. orders [redacted] shipped 4th Class [redacted] Post. Canada *must* remit in U.S. funds drawn [redacted] U.S. banks. •Canadian orders [redacted] shipped International Book Post—add $12.50 shipping/handling. Applicants outside the U.S. and Canada will receive special ordering instructions. A shipping/handling charge & sales tax will [redacted] added to all orders. ©1995 EEBC IEEE295

[redacted] $51.00
Counts as 2

0415250-XX $57.19
Counts as 2

002469 $55.00

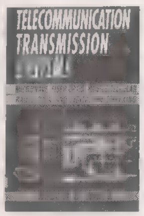
037603-XX $59.50
Counts as 2

044847 $40.00

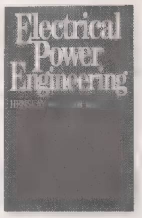
025354 $30.00

3991P $26.95
Softcover

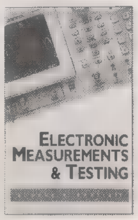
[redacted] $32.95



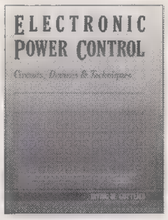
070964-XX $70.00
Counts as 2



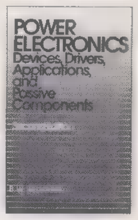
033157X $55.00



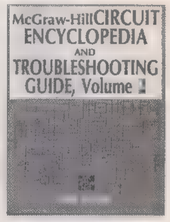
003961 $40.00



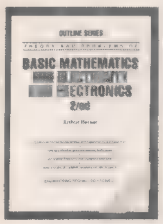
3837H $27.95



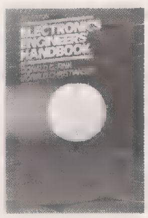
070439-XX $60.00
Counts as [redacted]



0376107 $59.50

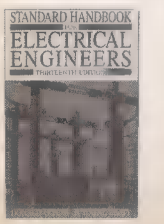


004439 $12.95
Softcover



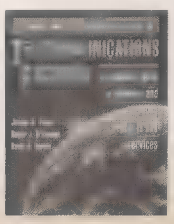
9255H-XXX $105.50
Counts as 3

037504 $39.50



020984-XXX $110.50
Counts as 3

0280401 $45.00



049183 $29.95
Softcover

As a member of the Electronics Engineers' Book Club . . .

. . . you'll enjoy receiving Club bulletins every 3-4 weeks containing exciting offers on the latest books in the field at savings of up to 50% off of regular publishers' prices. If you want the Main Selection do nothing and it will be shipped automatically. If you want another book, or no book at all, simply return the reply form to us by the date specified. You'll have at least 10 days to decide. If you ever receive a book you don't want due to late delivery of the news, you can return it at our expense. And you'll be eligible for *FREE* BOOKS through the Bonus Book Program. Your only obligation is to purchase 3 more books during the next 2 years, after which you may cancel your membership at any time. IEEE295

If you select a book that counts as 2 choices, write the book number in one box and XX in the next. If you select a counts as 3 choice, write the book number in one of box and XXX in the next 2 boxes. All books are hardcover unless otherwise noted. Publishers' prices shown. A shipping/handling charge & sales tax will be added to all orders. ©1995 EEBC

If card is missing, write to:
Electronics Engineers' Book Club, A Division of McGraw-Hill, Inc.,
Blue Ridge Summit, PA 17294-0860

BUSINESS REPLY MAIL
FIRST CLASS MAIL PERMIT NO. 4474 COLUMBUS, OH
POSTAGE WILL BE PAID BY ADDRESSEE
ELECTRONICS ENGINEERS' BOOK CLUB®
A Division of McGraw-Hill, Inc.
P.O. Box 182601
Columbus, OH 43272-3028
NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

dawn_farry@barney.info.sunyit.edu.

Industrial Automation and Control (IA); May 22–27; National Taipei Institute of Technology, Taiwan; Paul I-Hai Lin, IU-Purdue University, 2101 Coliseum Boulevard East, Fort Wayne, IN 46805; 219-481-6339; fax, 219-485-4269; e-mail, lin@smtplink.ipfw.indiana.edu.

International Conference on Robotics and Automation (RA); May 22–27; Nagoya Congress Center, Nagoya, Japan; Toshio Fukuda, Department of Mechano-Informatics and Systems, Nagoya University, Furo-cho, Chikusa-Ku, Nagoya 464-01, Japan; (81+52) 781 5111, ext. 4478.

International Symposium on Power Semiconductor Devices and Integrated Circuits (ED); May 23–25; Yokohama Convention Center, Japan; Toshiaki Yachi, Nippon Telegraph & Telephone Corp., NTT Interdisciplinary Research Laboratory, 9-11, Midori-Cho, Musashino-shi, Tokyo 180, Japan; (81+422) 59 3129; fax, (81+422) 59 2172.

International Symposium on Electron, Ion and Photon Beams Symposium

e-mail, e.nagel@ieee.org.

37th Cement Industry Technical Conference (IA); June 5–8; Caribe Hilton Resort and Casino, San Juan, Puerto Rico; Jose A. Alustiza, Puerto Rican Cement Co., Box 364487, San Juan, PR 00936-4487; 809-783-3000; fax, 809-781-8850.

Eighth International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems (C); June 5–9; Hilton on the Park, Melbourne, Australia; Moonis Ali, Department of CS, Southwest Texas State University, San Marcos, TX 78666-4616; 512-245-3409; fax, 512-245-8750; e-mail, ma04@academia.swt.edu.

Symposium on VLSI Technology (ED); June 6–8; Kyoto Grand Hotel, Japan; Hiroyoshi Komiya, ULSI Laboratories, Mitsubishi Electric, 4-1 Mizuhara, Itam-ishi, Hyogo 664, Japan; (81+727) 82 5131; fax, (81+727) 80 2685.

International Conference on Consumer Electronics—ICCE (CE); June 7–9; Westin Hotel O'Hare, Rosemont, Ill.; Diane D. Williams, 67

Continued on p. 66E1

washington watch

Clinton White House to shake up government

Plans to cut nearly $20 billion in five departments and agencies were announced in December by the Clinton administration. The R&D community would be affected mostly by changes in the Department of Energy (DOE) and the Federal Aviation Administration (FAA).

DOE would suffer the largest cuts: $10.6 billion over five years. Details must be worked out with Congress, but some $1.2 billion would come from "applied research programs." The utilities will see the Clean Coal Technology program cut.

But it would be premature to predict the end of the fusion program or what would happen with the DOE's heralded national laboratories, some of which have annual budgets in excess of $1 billion, according to Deputy Energy Secretary Bill White.

A commission on the future of the labs, headed by James Galvin, former Motorola Inc. chairman, is due to report before this month is out.

Meanwhile, the FAA would transfer its operational role for air traffic control (and some 40 000 employees) to a semipublic corporation supported by fees. The approach has been urged for some time [see *IEEE Spectrum*'s special report on air traffic control, February 1991, pp. 22–36]. It now has a greater chance of being passed by a Republican Congress.

Republicans attack Federal R&D . . .

Among the programs being eyed for cancellation by the Republican majority in Congress are the two centerpieces of the Clinton administration's technology policy: the Technology Reinvestment Project and the Advanced Technology Program.

In a letter to the White House on Dec. 5, Senators John McCain (R-Ariz.) and John Warner (R-Va.) urged Clinton to lop nearly $8 billion from fiscal year 1995 programs that are "wasteful" and "contribute little, if anything, to our defense posture."

On their list were the $550 million Technology Reinvestment Project, $1.5 billion worth of defense conversion programs (including manufacturing technology and advanced simulation), and $1.1 billion of university research.

In addition, the Republican staff of the House Budget Committee has put together a list of possible cuts, which includes killing the Advanced Technology Program, shrinking the High Performance Computing Program, reducing spending on energy technology development, and lowering the overhead rate through which universities are compensated for government research. Funding for the National Science Foundation and the National Oceanic and Atmospheric Administration would be frozen.

. . . others defend its value at IEEE-USA symposium

Champions of Federal support for technology warned against too many cuts at an IEEE–United States Activities forum held Dec. 12–13 at the Johns Hopkins University Applied Physics Laboratory, Laurel, Md.

The high-risk technological development undertaken by the Advanced Technology Program is needed by industry, argued Brian Belanger, deputy director of the mortally threatened program. Taxpayers will benefit in the long term, he said, from the resulting increase in high-paying jobs and economic growth.

Federal support through the jeopardized Small Business Innovation and Research program was credited by Gene Banucci with helping to make his company a thriving high-tech manufacturer. Banucci is chief executive officer of Advanced Technology Materials Inc., which produces environmental control equipment, industrial diamonds, and flat-panel displays and pays over 100 employees each $47 000 or more per year.

Dual-use research (which is also under attack) was plugged as a way to create government-industry partnerships by Dwight Duston, director of innovative science and technology in the Pentagon's ballistic missile defense organization. According to Duston, "most technology is dual-use, even when it's not obvious."

For more information, contact IEEE-USA, 1828 L Street, N.W., Washington, DC 20036-5104; 202-785-0017; fax, 202-785-0835.

Roadblocks on the info highway

Resistance to change will prevent people and organizations from capitalizing on the information infrastructure, predicts a report, *Breaking the Barriers to the National Information Infrastructure*, by the Council on Competitiveness, Washington, D.C.

Among the findings: few NII applications have been brought to market despite their great potential; an uncertain legal and regulatory environment is hampering applications in fields such as health care; and lack of interoperability frustrates users as they try new tools.

The report, based on a September conference, examines the areas of manufacturing, education, electronic commerce, health care, and entertainment. It also looks at 28 technology demonstrations.

Copies are available for $28 by calling the council at 202-682-4292. The report is available electronically from a server called iitf.doc.gov.

Green technology pays

A conference convened here by the White House in December to boost environmental technology touted it as "one of the most promising sources of new, sustainable, high-paying jobs."

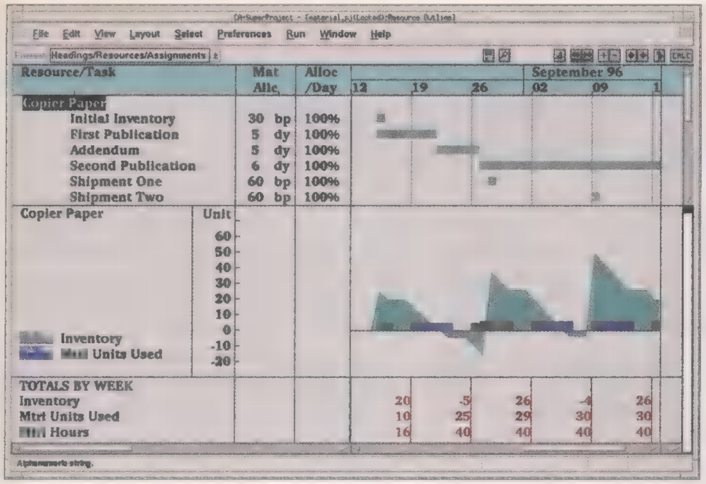
Currently, the United States leads the world in this field. According to White House estimates, some 45 000 U.S. companies employ more than 1 million people and make about $134 billion in the field. Yet both Japan and Germany have greater exports in the area.

The U.S. government spends about 50 percent of its environmental R&D on pollution avoidance; 30 percent on monitoring and assessment; 15 percent on remediation; and 5 percent on pollution control.

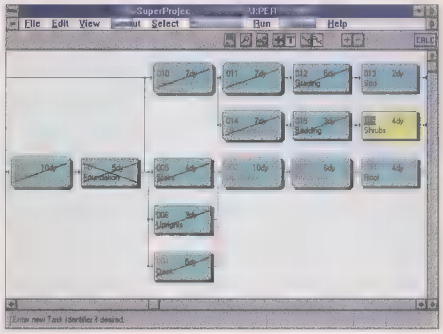
Industry funds about 90 percent of the developments in environmental technology. The conference, which was the culmination of the work at some 20 regional workshops, seeks to better coordinate industry and Federal participation.

Included in the conference packet were floppy disks to enable access to the Global Network for Environmental Technology (GNET), where the conference was expected to continue on-line via workshop results, e-mail, and discussion groups. More information is available from etcomments@nsf.gov.

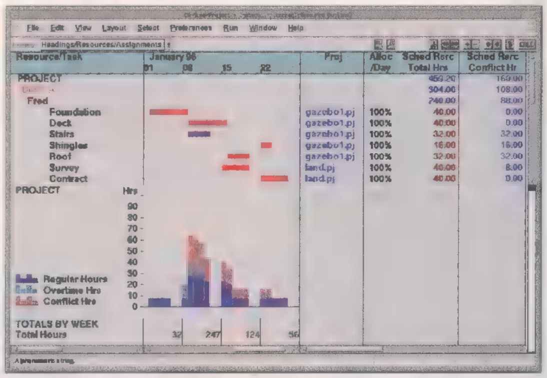
JOHN A. ADAM, ***Washington Editor***



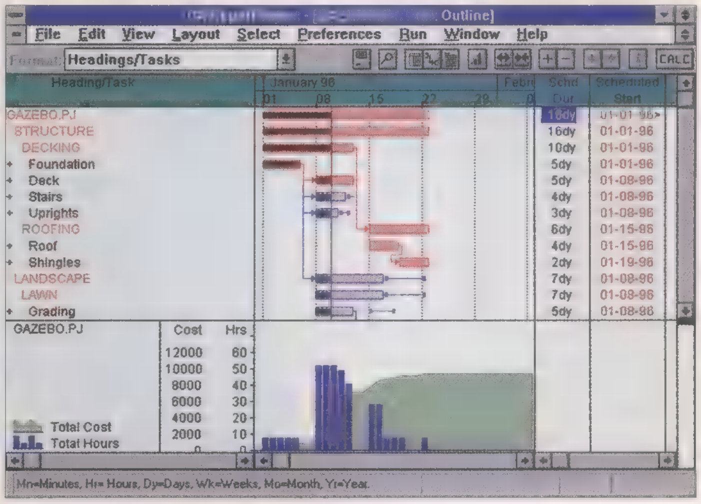
Track and manage the production, inventory and use of materials in addition to the management of labor, equipment and other resources.



Change project views to see WBS or PERT charts showing dependency links, milestones and status.



View project status quickly and easily to anticipate and avoid costly project delays.



State-of-the-art graphics and reporting capabilities make your data easier to understand.

If PERT Charts, WBS Structures And Comparative S-Curves Get You All Excited. This Will Really Spin Your Hard Drive.

Serious project managers need software that's as serious about the job as they are. And that software is CA-SuperProject®.

Powerful yet flexible, SuperProject is sophisticated enough to reflect your work environment and is incredibly easy to use.

Model your projects realistically with effort-driven tasks, date constraints, large capacities, to-the-minute scheduling, flexible progress tracking, auto actuals, re-scheduled remaining effort and strong multi-project management.

Manage resources and costs efficiently with multiple calendars, availability and rate tables, efficiency factors, shifts, overtime, materials management, advanced leveling, rate overrides, fixed and overhead costs, cost accounts and cost/schedule reporting.

Understand, report and present your projects effectively using four unique outlines with integrated Gantt and histogram charts, crosstabs, PERT and WBS charts, S-Curve and other cost charts, full customization with unlimited saved layouts and 90 user-defined fields and formulas, all in an intuitive WYSIWYG environment.

Call 1-800-225-5224, Dept. 62188, For More Information.

CA-SuperProject for the serious power user. You'll wonder how you ever managed without it.

New CA-SuperProject® 3.0

UNIX Windows OS/2

COMPUTER ASSOCIATES®
Software superior by design.

Circle No. 20

faults & failures

Biology 101 on the Internet: dissecting the Pentium bug

"It appears that there is a bug in the floating point unit of many, and perhaps all, Pentium processors," began an e-mail note from Thomas R. Nicely, a professor of mathematics at Lynchburg College, in Virginia. The note was sent on Oct. 30 to a few individuals with a professional interest in the Pentium chip, the flagship microprocessor of Intel Corp., Santa Clara, Calif. It was the mild-mannered beginning of the most widely publicized hardware bug in computer history.

Professor Nicely stumbled on the bug in the course of his ongoing study of prime numbers, during which he routinely takes their reciprocals. While working with his Pentium system, he discovered that one inverse—the now famous Nicely's prime that has been presented in news magazines and other publications—gave the wrong result.

A number multiplied by its inverse should equal 1, and on most machines, it does. But, in this case, when Nicely multiplied the numbers (824633702441.0) and (1/824633702441.0), he obtained a total of 0.999999996274709702. While close enough to 1 for most of us, it is a far cry from the accuracy that was claimed for the chip.

Out of the bag

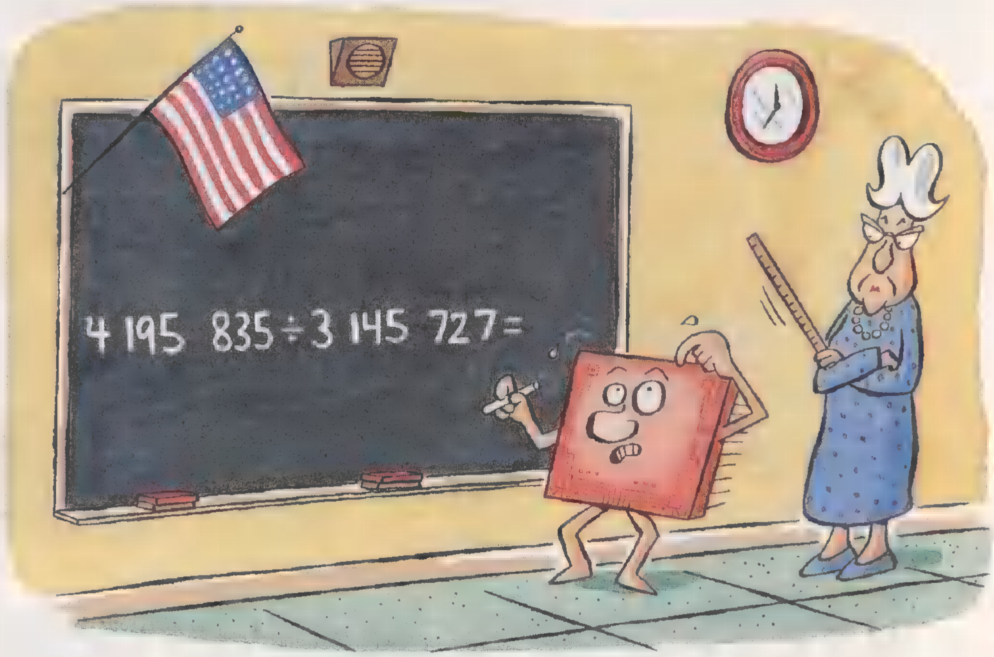
Within days, Nicely's original message appeared in the Internet newsgroup comp.sys.intel. Soon, the group's members were abuzz with alarm and confusion over the bug's possible impact on the accuracy of their calculations.

Within a week, the story broke in the Nov. 7 issue of *Electronic Engineering Times*. Alexander Wolfe, who had been following the newsgroup discussions, reported that Intel had itself discovered the bug early last summer, had corrected the masks, and had begun production of chips without the flaw. But systems with flawed chips went on being sold, and end-users were kept in the dark. The company apparently believed the problem to be a mere speck on the horizon not worth any fuss or even acknowledgement.

But owners and manufacturers of Pentium systems, suppliers of mathematical software, mathematicians, and computer scientists wanted answers. The din of their electronic discussions was deafening, and Intel was forced to listen.

The company attempted to calm the roiled waters by describing as a "subtle flaw" what the Internet community was by this time calling a "glaring FDIV bug." (FDIV is the instruction for floating-point division.) In a fax document (No. 7999) that was circulated on the Internet on Nov. 24, the company reported that its analysis had found the probability of occurrence to be one divide in 9 billion, or once in 27 000 years for the average spreadsheet user. Intel offered to work with anyone who had a problem with a Pentium system, particularly those who were involved with complex mathematics or the generation of prime numbers. The concerns of more conventional users were dismissed. "If you don't [use such mathematics], you won't encounter any problems with your Pentium-based system," declared the message.

Far from mollified, the online community set about doing its own analysis of the bug's causes, probability, and severity. By now, reports of other numbers that evoked the bug were being posted in the newsgroup. At Vitesse Semiconductor Corp., Camarillo, Calif., Tim Coe, a semiconductor design engineer, thought he saw a pattern in the reported errors. He found that many of them differed by factors of two, and when written in binary form, had similar mantissas (numbers to the right of decimal points).



PETER WALLACE

Using this insight, he wrote an equation that described almost all the known problem numbers, which in turn contained clues to the Pentium's floating-point architecture. As a former designer of floating-point units, he was able to create a model of the Pentium's floating-point division architecture that predicted almost all of the observed errors. Having no easy access to a Pentium system, Coe wrote his model on a Sun Microsystems desktop system and fed in numbers known to cause errors. As he watched the divisions unfold, he noticed that the failing numbers typically built up a string of 1s in the partial remainders. He soon divined that the asterisk divisors must occur in bands just a tiny fraction below the integers 3, 9, 15, 21, and 27, or their binary scalings (that is, these numbers multiplied by a power of two).

Coe then realized that he could increase the amount of the relative error. "Up until this point I was dealing only with reciprocals," he told *IEEE Spectrum*. But by varying the dividend, he made the error occur earlier in the division process, increasing its severity. The largest error he was able to predict occurred when he divided 4 195 835 by 3 145 727. The result of this calculation when multiplied by the original divisor should give back the original dividend. So, predictions in hand, he went off to a local computer store and commandeered a Pentium system. On the buggy machine, Coe found the answer to be off by 256, or a whopping one part in 16 000.

At the heart of it

Coe's model was not far off. Following his analysis, Intel on Nov. 30 came clean with a white paper by numerics architect H.P. Sharangpani and computational scientist M.L. Barton that described the bug and its potential consequences in detail. The paper is available from Intel through the company's World Wide Web server (http://www.intel.com) or by calling the Intel customer support line, 800-628-8686.

The bug resides in a programmable array that is used during floating-point division. In order to speed up the operation, Intel designers changed their tried-and-true method for floating-point division from the standard shift-and-subtract approach used in the 486 microprocessor to an algorithm called radix 4 SRT—after the initials of the three men who independently developed the technique more than 30 years ago. The approach allows 2 bits of quotient to be generated every clock cycle and so doubles the speed of the calculation. During the division, a plot of partial remainders versus divisors, called a P-D plot, is used to select the next quotient digit. In the Pentium implementation, this plot is stored in a look-up table. It is here that calculations begin to go awry.

According to the white paper, "After the P-D plot (lookup table) was numerically generated, a script was written to download the entries into a hardware PLA (programmable lookup array). An error was made in this script that resulted in a few lookup entries being omitted from the PLA. As a result of this omission, a divisor/remainder pair that hits these entries during the lookup phase of the SRT algorithm will incorrectly read a quotient digit value of 0 instead of +2."

The paper further confirmed five ranges of at-risk binary divisors, namely, those beginning with 1.0001, 1.0100, 1.0111, 1.1010, and 1.1101. (These binary numbers correspond to the at-risk divisors deduced by Coe.) The Intel scientists observed that these bit patterns had to be followed by a long string of 1s to boost the probablity of error.

Such mistakes happen, and Intel's critics did not fault the company for this mishap. Rather, they blamed it for not notifying the public about the bug much earlier, for deprecating its seriousness, for persisting in selling the flawed chips, and, at least at first, for requiring the owners of Pentium systems to justify their need for a replacement chip.

Do it with software

Suppliers of mathematics software were understandably concerned. Cleve Moler, chairman and chief scientist of The MathWorks Inc., got together with Tim Coe and Terje Mathisen, a computer programmer at Norway's Norsk Hydro, to devise a way to avoid activating the bug. Even before Intel's white paper came out on Nov. 30, these scientists had gained a good enough understanding of the bug from Coe's analysis to contrive a software workaround.

They disseminated a description of their solution on the Internet: "The test involves looking only at the denominator, although the numerator also affects whether or not an error actually occurs. If the denominator is found to be outside the at-risk bands, the FDIV instruction can be safely used to produce the correctly rounded IEEE [standard] result. If the denominator is in one of the at-risk bands, then scaling both the numerator and denominator by 15/16 eliminates the risk. Moreover, if the scaling and the subsequent FDIV instruction are carefully carried out in the extended precision format, it is still possible to produce the correctly rounded result."

Later, in order to incorporate the trio's solution in a form of use to compilers and compiler libraries, Intel invited Coe, Moler, and Mathisen to join forces with Peter Tang, a computer scientist from Argonne National Laboratories, and a team of Intel engineers. Intel has now posted the workaround on its World Wide Web Server.

Black and blue

Even with the underlying causes of the bug out in the open and a software solution well under way, the frequency and severity of the flaw were still issues of hot debate.

Vaughan Pratt, professor of computer science at Stanford University, California, saw Tim Coe's list of at-risk divisors and recognized that they fell into the class of what he called "bruised integers"—numbers close to but slightly less than integers, 2.999999, for example. He argued that in some applications these numbers can occur with more than random frequency because of roundoff errors incurred in previous calculations. Pratt estimated that errors could occur as infrequently as once every 40 billion floating-point divisions for perfectly random number pairs, on up to one division in a few thousand for more susceptible applications.

Scientists in IBM Corp.'s research division reached the same conclusion. With IBM a major manufacturer of Pentium systems, as well as a maker of the competing PowerPC chip, its interest was more than academic. "Our analysis shows that the chances of an error occurring are significantly greater when we perform simulations of the types of calculations performed by financial spreadsheet users, because, in this case, all bit patterns are not equally probable," they reported. At-risk denominators can occur far more often when they are "created by adding, subtracting, multiplying, or dividing numbers." For these types of calculations, IBM concluded, errors may occur once out of every million divides.

On the basis of its analysis, IBM announced on Dec. 12 that it had stopped shipping Pentium-based machines until the issue could be resolved.

Finally, after weeks of criticism that left Intel's image more bruised than Pratt's integers, the company switched to a replacement policy based on customer request rather than customer need. The company will take an unspecified material charge against fourth-quarter earnings to pay for the replacement chips. Those who wish to have their flawed Pentium chips replaced should call 800-628-8686.

But the time and energy that went into the understanding of the bug by the *cognoscenti* of computer science and mathematics is mind-boggling. Professor Nicely searched for four months for the source of his errors—first in his programs, then in his compiler, and finally in his Pentium microprocessor. Tim Coe spent much of his spare time for more than a month analyzing the pattern of failures in order to reverse-engineer the chip's floating-point division architecture. Not having his own Pentium system, he shuttled between his office and the closest Comp USA computer store to test out his model. Vaughan Pratt wrote a volume on the Internet establishing the significance of the bug and showing that its consequences reached much farther than Intel's statements were indicating.

These scientists and others did all of us a service by digging deep into the causes and ramifications of the bug and so precipitating Intel's no-questions-asked replacement policy. But in the process they spent valuable time and effort on something that could have been a non-problem, had Intel been more forthcoming.

LINDA GEPPERT, **Associate Editor**

RADIO ASTRONOMY: NEW WINDOWS ON THE UNIVERSE

GLENN ZORPETTE
Senior Associate Editor

FLUSHED AND TALKING EXCITEDLY, W. Miller Goss is one happy radio astronomer. Eleven thousand light years away, in the southern constellation of Scorpio, a mysterious object about the size of a double-star system is ejecting electrons at more than 90 percent of the speed of light. Only one other such episode has been seen, just eight months earlier, puzzling astronomers because they had never seen something so small expel a jet so fast and furious. The most probable cause, they believe, is the suction of nuclear material from a regular star toward a superdense companion, such as a black hole.

In the halls outside Goss's office at the National Radio Astronomy Observatory (NRAO) in Socorro, N.M., the enthusiasm is palpable as radio astronomers hurry back and forth and talk animatedly about the big news. Goss, an assistant director of the NRAO, oversees not only the operation at the heart of the present hubbub, but also the Very Large Array of 27 radio telescope dishes in the desert west of Socorro (photo, these pages). At this moment, though, his attention is mainly on the organization's other, even-more-sprawling asset: the Very Long Baseline Array (VLBA), a group of ten 25-meter dishes scattered among U.S. locales between the island of Hawaii and St. Croix, in the Virgin Islands. (Headquartered in Charlottesville, Va., the NRAO is operated by Associated Universities Inc., a private academic consortium, on funds from the National Science Foundation.)

Like a child experiencing his first snowfall, Goss can barely contain his glee. "We've just made the decision to scrap the original VLBA schedule this weekend," he tells a visitor. "This thing—we've got to observe it as soon as we can."

Besides being the closest manifestation ever of a possible black hole, the phenomenon may give researchers greater insight into gravity, a surprisingly complex force whose fuller exposition is crucial to a variety of theories on the origin and fate of the universe. "The problem," Goss explained, "is how can you make gravity work to produce so much energy?" Such theories, he added, will benefit from detailed observations of the mysterious object, which, though 10^{20} meters distant, is practically a neighbor in universal terms. "It's the kind of source that, in our own galaxy, we didn't know existed a year ago," he amplified.

Less peaceful, more exciting

Although unusually promising, the double-star observations are in a way typical of the contributions of radio observations to traditional astronomy. Far from being a mere adjunct to optical techniques, radio astronomy has time and again revealed quite remarkable classes of objects, profoundly altering scientists' basic understanding of the universe. "Radio astronomy revolutionized astronomy because by showing us things like quasars, pulsars, and radio

galaxies, it turned our universe into something more violent, less peaceful, and more exciting than what was seen before," Goss said.

Now, 63 years after pioneering observations by Karl Jansky, a 27-year-old electrical engineer at Bell Telephone Laboratories, radio astronomy is a robust and thriving discipline, whose practitioners operate dozens, if not hundreds, of instruments spread among all the world's continents. Thirty-three years after Jansky picked up a steady hissing from the center of the Milky Way, the budding discipline had one of its greatest triumphs, when Arno A. Penzias and Robert W. Wilson, also of Bell Labs, discovered radiation that uniformly permeates space at 2.7 K. This radiation is a hypothesized remnant of the universe's primordial explosion—the "big bang" in which it expanded by a factor of 10^{90} in a period of perhaps 10^{-35} second. This cosmic microwave background radiation is considered one of the strongest pieces of evidence for the big bang, and its discovery won a Nobel prize for Penzias and Wilson in 1978.

Today, radio waves in various bands are routinely used to study physical and chemical phenomena as close as the earth's atmosphere and as far away as the powerful, enigmatic quasars that are monitored as they were when the universe was only perhaps 5 percent of its present age. They may be as many as 13 or 14 billion years old; a more precise number depends on the age of the universe itself—anywhere from 8 to 15 billions of years, depending on which model is used to calculate it.

Almost 20 percent of all discrete radio sources discovered in the universe have no detectable optical image, strongly suggesting that they are quasars or other powerful sources too far away to be seen. Radio astronomy has also let astronomers "see" the center of our own galaxy, where stars are being born but which is largely obscured to optical instruments by interstellar dust. Radio instruments can make images with finer resolution than anything achievable with optical means, and have made possible the discovery and analysis of a variety of molecules in interstellar space and in faraway galaxies.

Another of radio astronomy's great contributions has been its revelation of the existence of pulsars, the rapidly spinning remains of old stars that have collapsed into an incredibly dense mass of neutrons with a circumference of about 100 km or less. The intense magnetic fields of pulsars generate radio waves that emanate in conical beams from their poles at frequencies typically between 50 MHz and 5000 MHz. As the poles of the pulsars precess, depending on their orientation, the radio beams may sweep across the earth. There they are perceived as radio pulses, with periods generally between a few milliseconds and 1 second.

Some 500 pulsars have been found in the Milky Way, but at least 200 000 are thought to exist. Of special interest are the short-period pulsars, which pulse every few milliseconds and are the most accurate clocks known. Another important group is made up of binary pulsars, which orbit stars while spinning on their axes. In particular, binary pulsars with fast orbital speeds and massive companions have proven invaluable for testing implications of the general theory of relativity. One of these is that a binary star system should lose energy in the form of waves of gravitational radiation, causing a slow decline in the orbital distances between the two stars. The phenomenon would be perceived as a gradual shortening of the orbital period, measurable through emanations from the pulsar. In fact, this effect has been observed in a system known as PSR 1913+16. The work, as well as their discovery of binary pulsars in the mid-'70s, earned U.S. physicists Joseph Taylor and Russell Hulse a 1993 Nobel prize.

Scattered over the plains of San Agustín in west-central New Mexico are the 27 antennas of the Very Large Array. Each is 25 meters in diameter. Their outputs are correlated and then processed to yield high-resolution images of the radio brightness of far-off galaxies, nebulae, and other objects.

PHOTO: RAY NELSON

Are they watching Milton Berle on Mu Arae III?

Do we share the universe with other intelligent beings? Since the extent and grandeur of the universe became known, no other scientific question has had quite the same hold on intellectually active members of the public. Countless papers have been written, books published, and hypothetical scenarios debated on the subject, which is known as SETI, for "search for extraterrestrial intelligence." At least one well-known astronomer has managed to turn the concept into a publishing and multi-media empire. But so far, say experts and long-time observers, not a single effort to discover and verify artificial radio signals of possible extraterrestrial origin has been sophisticated and extended enough to have a reasonable chance of success.

This month, though, at a 33-year-old radio telescope in Parkes, New South Wales, Australia, a small team is to begin a six-month project that will be technologically the most advanced effort to date. The heart of their equipment is a multichannel signal analyzer. To be installed on the 64-meter–diameter dish at Parkes, the analyzer resolves 20 MHz worth of spectrum into channels as narrow as 1 Hz separated by 0.75 Hz. Signals with such narrow bandwidths are favored because they are more likely to be of artificial origin. Channels that are 2, 4, 7, 14, and 28 Hz wide will also be analyzed. Individual stars are to be examined over a spectrum of 1–3 GHz, using one hundred 300-second observations in steps of 20 MHz.


SCOTT MATTHEWS

One of the most practical features of the equipment, however, is its ability to continue searching while it attempts to verify previously received signals that showed signs of intelligence. Searches of this kind are often interrupted by "false alarms," stray signals from military radios, commercial broadcasts—and, fortuitously in 1967, a pulsar. In the Parkes search, the celestial coordinates of an apparent strong continuous or pulse signal will be noted, and the follow-up carried out with an alternate receiver on the same antenna, plus a second receiver on another antenna some 200 km to the north. With two antennas, the difference in Doppler shift at the two locations makes it easy to reject signals coming from sources closer than the stars.

At least as remarkable as the equipment is the project's tortuous history. It was born in 1971, when the NASA Ames Research Center in Northern California invited Bernard ("Barney") M. Oliver, then of Hewlett-Packard Co., to conduct a "Design Study of a System for Detecting Extraterrestrial Intelligent Life." The resulting report, "Project Cyclops," was the basis for the ensuing 22-year NASA SETI program.

In the fall of 1993, after NASA had invested $78 million, everything came to a screeching halt. Declaring it wasteful of taxpayers' money, Senator Richard H. Bryan (D-Nev.) stripped the fiscal 1994 budget of the project. He had accomplished what Senator William Proxmire (D-Wis.) had tried so hard to do all through the '70s and '80s.

"After the cancelation, we asked ourselves, 'Are we just going to go belly up?'" recalled Oliver, now vice president emeritus of Hewlett-Packard, an IEEE Life Fellow, and senior technical advisor to the SETI Institute in Mountain View, Calif. They would not, thanks to five high-technology pioneers with deep pockets and expansive vision: William Hewlett, David Packard, Gordon Moore, Paul Allen, and Mitchell Kapor pledged a total of $4–$5 million, the core of a purse that eventually reached $7.5 million. The sum saved the targeted search and set the stage for this month's inaugural run at Parkes. Officially, the receiving equipment is being lent by NASA to the private SETI institute for the project.

To keep the targeted search and its costs manageable, a few hypotheses had to be made about how extraterrestrials would attempt to get in touch. "We're going on the assumption that there would be beamed signals," Oliver said. "For nearby stars, that's not a bad assumption." Within 100 light years (950 million million kilometers) of the earth, in the "solar neighborhood," are about 1000 stars. Extraterrestrials trying to make contact within this tiny corner of the galaxy would be likely to beam signals at other stars; and over larger volumes of space with more stars, so many beams would have to be used that the signal might as well be sent omnidirectionally.

Presumably this approach would be eschewed, because of the fantastic transmit power or unimaginably gigantic receive antennas that basic physics would dictate. The same principles, incidentally, make it highly unlikely that extraterrestrials are watching Milton Berle in other solar systems, regardless of what the popular press may say.

It is also deemed likely that the pulses sent would be a second or several seconds long, rather than micro- or milliseconds long. The detectability of a pulse depends only on its total energy, so a very short one would require sudden, and relatively high, peak power.

The chances of finding an extraterrestrial signal depend on how widespread life is among our galaxy's 200 billion stars. On this point there is little agreement; the extremes are represented by those who argue there is no other life whatsoever in the Milky Way, and by astronomer Carl Sagan and others who just as earnestly tout up to a million advanced civilizations. To put this in perspective, even if there are a million advanced civilizations in the galaxy, some 200 000 stars would have to be examined in order to give good odds of hitting upon one with a civilization. So the current search of about 1000 stars is not exactly a sure thing.

As is so often the case with science, though, something utterly unforseeable might be found. "We might discover something quite different from intelligent life—like some new astrophysics, that might help keep [the SETI project] alive," said Oliver. After all, when scientists first received radio waves from pulsars, they thought for a while that they had come across signals from extraterrestrial beings. The reality was not quite so stupendous—but still one of the most valuable astronomical discoveries of the last quarter-century.

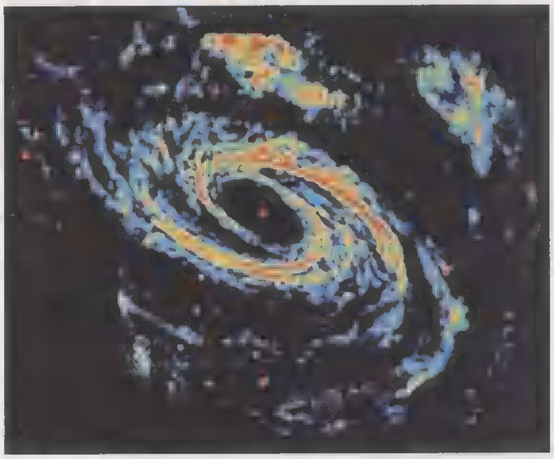
—G.Z.

Behind this impressive history of discovery has been an equally distinguished run of technological innovation. "As a science, astronomy is different because we can't interact with our experiments—we can only observe," said Patrick Palmer, professor of astronomy at the University of Chicago in Illinois. "So most advances have come from new technologies."

"Radio astronomy is one of the most interesting applications in all of electrical engineering," added scientist Peter J. Napier, who is on the basic research staff at NRAO. "We need the absolute largest and most accurate antennas, and the most sensitive, highest-frequency receivers, and the highest-speed, broadest-band digital electronics. It pushes all areas of electrical engineering. You'll never find an astronomer who'll tell you his antenna is big enough, or his receiver sensitive enough, or his backend broadbanded enough."

Nowadays, many of the technical advances reflect two basic trends: interferometry, in which the signals from multiple antennas are electronically combined to simulate the resolution attainable with a single, very large antenna; and the reception of shorter and shorter wavelengths. In the early years, radio astronomers used mostly wavelengths in the meter and centimeter range; since the '70s, though, more and more work has been based on millimeter and lately even submillimeter waves. Shorter wavelengths mean higher resolution and also the ability to detect certain molecules with relatively high-frequency spectra.

PALOMAR OBSERVATORY



NRAO/AUI

▲ Optical and radio images of the same galaxy—M81 in the constellation Ursa Major—together convey far more information about it than either does alone. In the radio image (bottom), the brightness of emissions from neutral hydrogen gas are shown in two colors, with red indicating the brighter radiation. The spiral arms extend much farther than in the optical image from the galactic center, indicating the relative abundance of hydrogen in the arms. The radio image's darkness around the galactic center, on the other hand, points to the lack of neutral hydrogen. Most probably, the gas has been used up in the formation of stars, a notion supported by the brilliance of the galactic center in the optical image.

The purpose of radio interferometry, in the refined form known as aperture synthesis, is cost-conscious improvement of the ability to resolve fine detail (the angular resolution is the angle subtended by the smallest visible details). With a dish-type radio telescope, resolution improves as the diameter of the dish antenna increases, so the largest possible dish is desirable. This guideline quickly reaches practical limits, however.

Interferometry offers a way around the problem by exploiting the interference patterns that arise when signals are received by multiple antennas. Signals arriving in phase at two antennas separated by some distance reinforce each other through constructive interference; those completely out of phase cancel. Thus a two-antenna system receives signals as a series of lobes in which the signals constructively interfere and are strong, separated by "nulls" where they are weak. This "fringe pattern" of lobes and nulls is created by the relatively minute differences in the distances from the far-off source to each of the two antennas. With enough processing, information about the fine structure of the source can be gleaned from the pattern and turned into images.

The farther apart the two antennas are, moreover, the finer are the lobes in the fringe pattern, and the higher their angular resolution. Roughly speaking, resolution of an interferometer improves as the distance between the antennas, known as the baseline, increases. At any given time, however, a single baseline can produce only limited information about the distant source. As antennas are added to the instrument, the number of baselines increases. If, moreover, each new baseline is unique in either length or orientation, it makes a new contribution to the information gathered about the structure of the source. As the earth rotates, the baselines move, giving each a "look" at different parts of the source.

The key technologies behind the technique are extremely low-noise radio receivers, highly stable and accurate time references, advanced digital electronics, special-purpose integrated circuits to perform fast Fourier transforms, and, in the case of continent-wide arrays, mass-storage systems that can handle data rates of up to 256 megabits per second.

At the Very Large Array, which is a "connected-element" interferometer, signals from all antennas are brought to a central point by a microwave waveguide system and combined in real time. But the Very Long Baseline Array, or VLBA, whose antennas are distributed across the United States, cannot operate in real time. Instead, the received voltage is digitally sampled as a function of time and recorded separately at each antenna on magnetic tape marked at regular intervals with ultra-accurate time references. Built in the late '80s and early '90s, the 10 antennas in the VLBA employ hydrogen masers having frequency stabilities of 2×10^{-15} in 1000 seconds.

In a process known as correlation, the output of each antenna is Fourier transformed and multiplied with that of every other antenna to yield the information needed to reconstruct the radio brightness distribution of the source. The process must take into account such factors as the elevation of each antenna, the distance between each pair, and the earth's curvature. At the VLBA's operations center in Socorro, a special-purpose system based on custom-designed chips does the correlating at an aggregate theoretical peak rate of 750 billion floating-point operations per second.

The final image-processing step uses the earth's rotation, in a procedure that NRAO spokesman David Finley likens to re-creating a picture seen through a slowly rotating colander: if the images seen through the holes are recorded instant-by-instant, and the details of the rotation known, the picture behind the colander can be pieced together. In astronomical terms, the process is known as "filling in the aperture."

From theoretical underpinnings that

were developed mostly by Australian and British engineers and scientists in the early '50s, interferometry matured in the '60s into a useful radio astronomical tool. Besides the VLBA, the world's largest and most sophisticated such instrument, and the companion Very Large Array, there are important interferometers in operation in Australia (at Narrabri), the Netherlands (the Westerbork Radio Observatory), and the United Kingdom. One of the UK telescopes, called Merlin, comprises seven antennas spread over 200 km in western and central England.

Whispers from the edge

At the meter- and centimeter-wavelengths typically received by the big interferometers, much of the radiation is relatively broad band, continuous, and the result of synchrotron emission: the radiation is caused by electrons spiraling in a magnetic field, such as the weak field that permeates interstellar space, or the much stronger fields in galactic cores.

Some of the most interesting, distant, and puzzling sources of synchrotron radiation are the so-called radio galaxies and quasars. Both are extraordinarily powerful—radio galaxies emit energy at 10^{10} to 10^{12} times the luminosity of the sun—for the most part from relatively small central regions. Quasars are even more powerful and are farther away, among the most remote objects in the universe, and receding at nearly the speed of light. In both cases, massive black holes are believed to be the only entities of such modest size (astronomically speaking) that could account for so much energy.

Continuous emissions such as these are the traditional mainstay of radio astronomy. But over the last decade or so, more and more work has gone into receiving and analyzing signals above about 70 GHz (wavelengths shorter than about 4 mm). Here, radio astronomy becomes almost a completely different discipline, with more complex receivers, and scientific rationales based more on chemistry than physics.

The entire endeavor owes its being, in large part, to advanced, ultra-low–noise mixing and amplification technologies developed over the last decade. The signals they receive often have traveled so far that they are at perhaps only a few thousandths of a degree kelvin and their frequencies have slowed by a factor of two or three because of red-shifting, the Doppler reduction in frequency of emissions from rapidly receding bodies. For example, spectral emissions from carbon monoxide in the recently discovered Cloverleaf quasar are received at 97 GHz, though emitted at 346 GHz.

Such signals are barely a whisper in the cacophony of system noise, and they require many hours of processing to yield their secrets. At these sensitivities and frequencies, a cloud in the earth's atmosphere drifting in front of the antenna can halve an already minuscule signal-to-noise ratio.

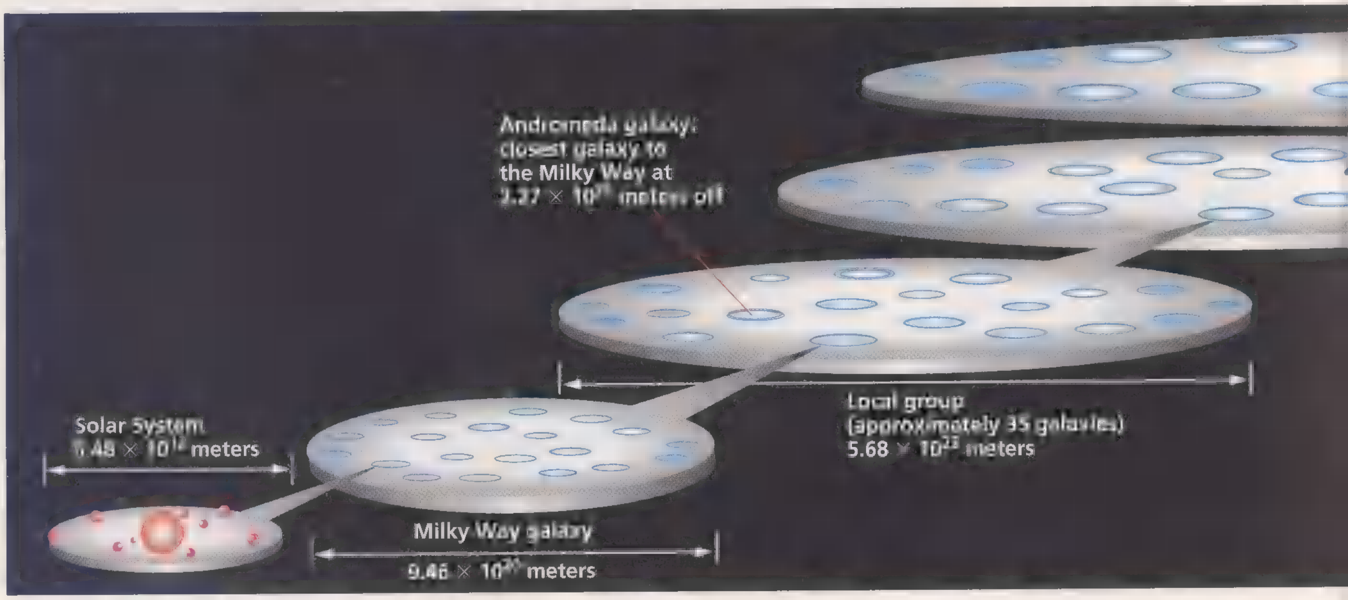
Virtually all receivers used in radio astronomy employ the super heterodyne technique, like ordinary AM or FM radios. In millimeter- or submillimeter-wave radio astronomy, the signal frequencies are too high to be manipulated as is, so they are mixed with the output of a local oscillator to produce a much lower "intermediate frequency," generally between 1 and 10 GHz. Even the local oscillator is a nontrivial piece of technology—it is based on a Gunn oscillator whose frequency output might be doubled, tripled, or quadrupled.

The most fruitful recent technology advances, though, have been in mixing and in amplification. Two signals are mixed when both are applied to a nonlinear device so as to create an assortment of intermodulation products, including, typically, a desired intermediate frequency. Any nonlinear device will do—but the sharper the nonlinearity, the less noisy the mixing. In the mixers now becoming standard in radio astronomy, known as superconductor-insulator-superconductor (SIS), the nonlinearity arises from the quantum tunneling between two superconductors separated by a thin dielectric.

The other fairly recent advance, in amplification, is the increasing use of amplifiers based on high–electron-mobility transistors (HEMTs). HEMT amplifiers are used to directly amplify received radio signals below about 50 GHz, and also to amplify the intermediate frequency produced by a mixer. Direct amplification with HEMTs of signals up to about 120 GHz is expected quite soon; this will let the amplifiers cover an appreciable fraction of the spectrum of millimeter-wave radio astronomy, which extends to 300 GHz.

The combination of SIS mixers and HEMT amplifiers has permitted engineers to build receiving systems that are literally almost as sensitive as can be. At some frequencies, stray photons from the background—the ground, the sky, the atmosphere, from within the telescope itself—are already overwhelming the contribution of the receivers.

In addition to these limits, SIS mixers will soon reach the so-called quantum noise limit, as determined by the Heisenberg uncertainty principle. For example, mixers at 3 mm work with photons whose energy corresponds to 5 K. Thus, even if the rest of the electronic noise is reduced to 0 K, the photon fluctuations alone will give the mixer a minimum noise tempera-



ture of 5 K. Already, the best of the SIS mixers come within a factor of about four of this limit.

Molecules in space

AN INVALUABLE CONTRIBUTION of millimeter-wave work has been in the field of astrochemistry. Interstellar space, if it could be created in a laboratory on earth, would be a very hard vacuum indeed, with about one molecule per cubic centimeter. However, in the great interstellar clouds, with their densities of 100 to 100 000 atoms per cubic centimeter, atomic gases become molecular. To date, about 100 molecules have been discovered in interstellar space, some of which are fairly bizarre ($HC_{13}N$, for example) and unknown on earth. Up until the late '60s, when the ammonia, water, and formaldehyde molecules were identified in the great interstellar voids, it was assumed that the density of radiation in these regions ruled out the formation of molecules. "This whole menagerie of interstellar molecules was completely a surprise, and completely contrary to prevailing theories," said the University of Chicago's Palmer.

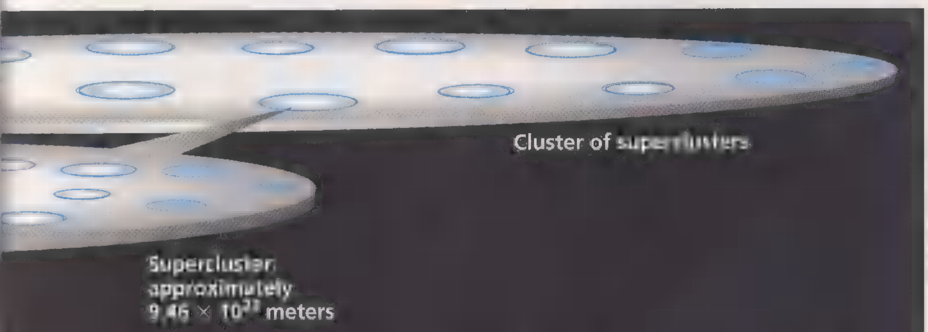
Detection of the molecules involves a form of spectroscopy. As the molecules' rotational frequencies undergo transitions from one quantum state to another, a photon is emitted at a precisely known frequency. The greater the energy gap of this quantum transition, the higher the frequency of the photon. Many, if not most, of these rotational lines are in the millimeter bands.

This relatively recent spectroscopy in the millimeter range is similar to that done since the '50s on the spectral line of atomic hydrogen, at 21.1 cm. Hydrogen is, in a sense, the basic building block of the universe, so the ability to map out its concentrations over vast regions is invaluable. "A lot of what we know about our own galaxy came from observations of hydrogen," said one NRAO scientist. About 10 percent of the mass of a galaxy like our own is atomic hydrogen, which tends to concentrate in the spiral arms. Since the atom's emission frequency is well known, the speeds at which galaxies spin can be computed from Doppler information.

The most useful molecular rotational line belongs to carbon monoxide, whose emission at 2.6 mm (115.3 GHz) was first observed in 1970 by a team from Bell Laboratories using the NRAO's millimeter-wave telescope on Kitt Peak in Arizona. The CO molecule is the second most abundant in the galaxy, behind molecular hydrogen (H_2), whose fundamental electronic emissions are in the ultraviolet and therefore all but undetectable on the earth's surface.

CO turns out to be a good indicator for H_2, and the simplicity of its emission spectra, as well as those of its isotopes, ^{13}CO and ^{18}CO, have given researchers insights into the physics and kinematics of interstellar clouds. Out of these clouds great stars are born, and CO, as a tracer of molecular hydrogen, renders parts of the process detectable. The ratios of ^{13}CO to ^{12}CO can even be measured—sometimes in other galaxies—making possible deductions about the density of the gas and transparency of the radiation.

The molecule has even been observed in far off galaxies, including some near the edge of the detectable universe. Atoms as heavy as carbon and oxygen are mostly created in the death throes of big stars, so the implications are significant. "What this means is that in the first two or three billion years of the universe, there's already been at least one cycle of the birth and death of massive stars," said a scientist at the NRAO's millimeter-wave telescope on Kitt Peak. "It puts a time scale on how fast things happened in the early universe. It indicates that the basic processes we observe today—stars being born, burning, and dying—were all happening early on."



Since they can detect powerful radio sources that are farther away than anything visible optically, radio telescopes have been useful in exposing the large-scale structure of the universe. Common extragalactic radio sources, like neutral hydrogen clouds, tend to be associated with galaxies or groups of galaxies and therefore fit into the clustering structure of the universe. Interestingly, the most distant known radio sources—quasars and very distant radio galaxies—seem not to follow this clustering pattern.

Source of figure: Hayden Planetarium, New York City

Another intriguing endeavor making use of millimeter waves is the search for ever more complex molecules, especially the kind involved in the development of life as we know it. A number of researchers are looking for amino acids, and *Science* magazine raised a few eyebrows with its issue last June 17, in which an article suggested that one had been found in space (researchers are now attempting to confirm or refute the results).

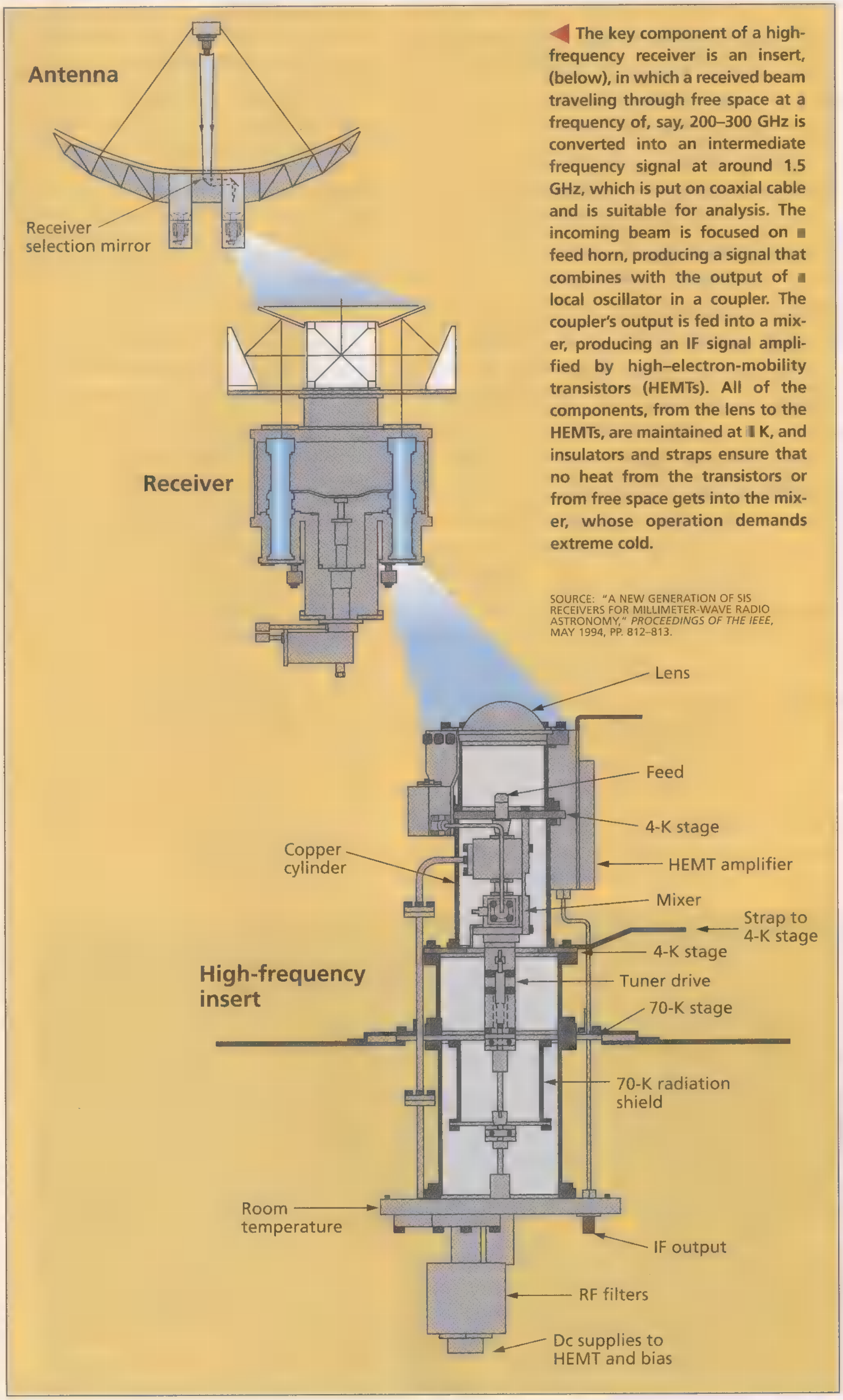
Perhaps the best millimeter-wave telescope in the world is the French-German-Spanish Institut de Radio Astronomie Millimétrique's 30-meter diameter dish high in the mountains of Spain's Sierra Nevada, not far from Granada. The telescope has been in operation for 10 years or so and makes extensive use of insulation, fans, and other components to control temperature and minimize thermal deformations. The receivers are installed in a large laboratory between the dish's elevation bearings, immediately behind the hole in the center of the reflector. Simple mirrors direct the received beam among the various receivers and calibration devices.

Other notable millimeter-wave instruments include the 45-meter–diameter Nobeyama telescope in Japan and the aforementioned 12-meter NRAO instrument on Kitt Peak, which covers almost the entire millimeter spectrum and discovered about half of all the molecules found in space so far.

Submillimeter telescopes receive frequencies of up to about 800 GHz, near the far infrared, as it were. The best of these is probably the 15-meter James Clerk Maxwell telescope, a British-Dutch-Canadian venture. Not far away on Mauna Kea, on the island of Hawaii, is the California Institute of Technology's 10.4-meter–diameter Submillimeter Observatory Department. A third telescope in this league is the 10-meter one recently completed on Mount Graham, near Tucson. It is run jointly by the Max Planck Institut für Radioastronomie in Bonn, Germany, and the Steward Observatory of the University of Arizona.

One measure of the staying power of the radio astronomical trends toward shorter wavelengths and interferometry is their merging into a third definable trend: millimeter-wave interferometry. Four pioneering interferometers are in operation, two of which are in California. The Owens Valley Radio Observatory, with six antennas, is run

by the California Institute of Technology, and at Hat Creek, the universities of California, Illinois, and Maryland also operate six antennas, with three more to join them soon. The other interferometers are at Nobeyama, Japan, and on the Plateau de Bure in France, where the Institut de Radio Astronomie Millimétrique operates an instrument comprising four 15-meter antennas (with a fifth to join them soon). Finally, a submillimeter array, with six 6-meter dishes, is under construction on Mauna Kea by the Smithsonian Astrophysical Observatory, based at Harvard University.



The key component of a high-frequency receiver is an insert, (below), in which a received beam traveling through free space at a frequency of, say, 200–300 GHz is converted into an intermediate frequency signal at around 1.5 GHz, which is put on coaxial cable and is suitable for analysis. The incoming beam is focused on ■ feed horn, producing a signal that combines with the output of ■ local oscillator in a coupler. The coupler's output is fed into a mixer, producing an IF signal amplified by high-electron-mobility transistors (HEMTs). All of the components, from the lens to the HEMTs, are maintained at ▮ K, and insulators and straps ensure that no heat from the transistors or from free space gets into the mixer, whose operation demands extreme cold.

SOURCE: "A NEW GENERATION OF SIS RECEIVERS FOR MILLIMETER-WAVE RADIO ASTRONOMY," *PROCEEDINGS OF THE IEEE*, MAY 1994, PP. 812–813.

Future instruments

None of these interferometers brings to the millimeter spectrum the kind of observing power that the Very Large Array near Socorro brings to the centimeter bands, however. The NRAO is campaigning for a "Millimeter Array" of 40 dishes, each 8 meters in diameter. The array would cover bands all the way from 30 GHz to 350 GHz, with emphasis on 200–350 GHz. If built, it would be the highest resolution millimeter-wave telescope, allowing astrochemists, for example, to image the distributions of carbon, oxygen, nitrogen, and sulfur—and their isotopes—in other galaxies.

"From my perspective, I think it would be a fantastic boon for the study of star formation," said the University of Chicago's Palmer. He cautioned, though, that the actual uses of major new radio telescopes often turn out to be much more diverse than the predicted ones, because fundamental discoveries frequently lead to entirely new fields of endeavor.

While radio astronomy in most parts of the world is concentrating on observations in the centimeter, millimeter, and sub-millimeter range, an intriguing project in India will permit observations in six bands between 38 MHz and 1420 MHz (7.9 meters and 21 cm, respectively). The Giant Metrewave Radio Telescope (GMRT) is under construction at Narayangaon, 82 km north of Pune. When completed, possibly later this year, it will have thirty 45-meter dishes spread over 25 km. Angular resolution is expected to vary from 75 arcseconds at 38 MHz up to 2 arcseconds at 1420 MHz.

The project is notable chiefly for its premise and its novel antenna design. The builders of the GMRT argued in a recent paper that "there are many exciting and

challenging astrophysical problems that are best studied at metre wavelengths.... Much of the potential has, however, remained unexploited as these instruments have been limited by sensitivity and resolution, as well as frequency coverage, and the inability of many of them to track radio sources for long periods of time."

The telescope, which is being built by India's prestigious Tata Institute of Fundamental Research, has many intended uses, but two stand out, according to Govind Swarup, the eminent radio astronomer who heads the project. It will be used to search for and study what are known as protoclusters, out of which clusters of galaxies arose in the early universe. It will also look for and study pulsars.

At the telescope's construction site, on the hot, dusty plain between the Meena and Kukadi rivers, Swarup explained the novel concept behind the telescope's antennas. The backing structure of each parabolic dish consists of 16 radial frames of tubular steel. Across these frames are stretched trusses of stainless-steel cables tensioned to near-parabolic curvatures, which in turn secure the reflective surfaces of the dishes. This lightweight, thin-wire mesh lets the wind slip through it, with an ethereal whistling and only slight shear forces on the antenna's foundation and structure. Each 45-meter dish is subjected to forces comparable to those of conventionally surfaced dishes 20 meters in diameter. All told, Swarup predicts the telescope will cost $16 million—about a fifth of what the Very Large Array cost in 1980.

Swarup's buoyant optimism that the GMRT will find "500 to 1500" more pulsars is partly based on the telescope's position:. Being closer to the equator than other big instruments, it will have more extended views of the center of the Milky Way, with its enormous profusion of stars.

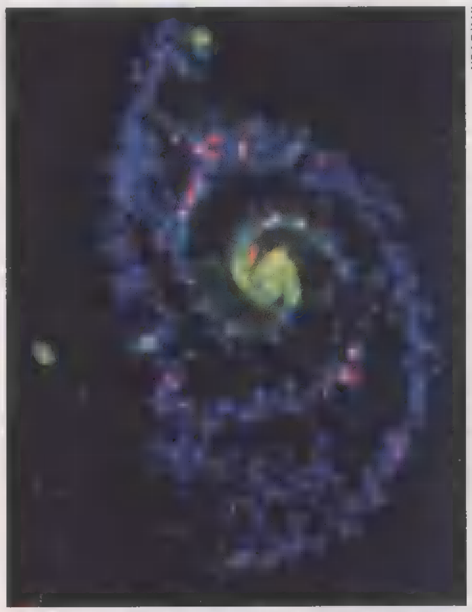
The same rationale lay behind a radio telescope recently completed on the paradisiacal Indian Ocean island of Mauritius, 2250 km south of the equator and 885 km east of Madagascar. Built by engineers from the Raman Research Institute in Bangalore, India, the telescope is jointly operated with the University of Mauritius in Réduit.

Its main purpose, according to engineer Uday Shankar of the Raman institute, is to comple a survey of the Southern Hemisphere sky at 150 MHz (2 meters), to complement the monumental Sixth Cambridge Survey at that frequency of the northern sky. Australia's impressive history in radio astronomy notwithstanding, the lowest-frequency survey of the southern sky was at 400 MHz, at which frequency the sky looks different enough to make the lower-frequency survey necessary, Shankar said.

Orbiting interferometers

Soon, interferometry will make its debut in space. Orbiting antennas can of course be spaced among baselines far longer than any on earth, and this is the incentive for Japanese and Russian projects that will orbit 8- and 10-meter–diameter dishes, respectively, in 1996 and 1997. The projects, known as VSOP and Radioastron, are separate but will overlap in their use of four U.S. groundstations.

Valuable though they have proven, interferometers are inferior to single antennas of similar aperture in their brightness sensitivity to extended features. Thus, the future of large, single-dish instruments seems assured, at least for the near-term.



NRAO/AUI

▲ **Three radio views of the whirlpool galaxy show the ionized hydrogen gas around very young stars (red), 21-cm continuum radio emissions from the same regions, as well as from electrons moving in magnetic fields (green), and radiation from neutral atomic hydrogen (blue).**

The most advanced such telescope, now being built by NRAO, is nearing completion at Green Bank, W. Va. Its mammoth, 100-meter dish will have a novel active surface comprising some 2204 panels, computer-controlled to minimize distortions. The technology permits reception of an enormous spectrum, down to the millimeter bands. Ordinarily, a dish of such size could never be made accurate enough to gather signals of such diminutive wavelength. In a sense, the telescope descends from one in Effelsberg, Germany, that was built in the late '60s. (Although the German telescope lacks active surface control, its ingenious design permits deformation into a family of parabolic surfaces that, depending on elevation, allow operation at wavelengths as short as 3 mm.

With an assortment of advanced projects coming on line in the next few years, radio astronomy appears ready for another leap into an inscrutable future. Along with the refinements in sensitivity and resolution will come the ability to more squarely address a few of the great, basic mysteries of cosmology, such as whether the universe began with the unimaginable expansion known as the Big Bang, or whether that was merely one of an endless cycle of expansions and contractions.

As it stands, theoretical models of how stars, galaxies, and clusters of galaxies form betray enough inconsistencies to have fostered a small but vociferous corps of skeptics of the Big Bang theory. According to classic Big Bang theory, for example, galaxies were mostly formed in the early universe. Yet galaxies of apparently widely varying ages have been observed. This fact, along with details of the clustering of galaxies and related questions about the existence of so-called "dark matter" (which cannot be detected directly), suggests the Big Bang theory is "trying to pass a straight line through a lot of randomly scattered points," to quote one skeptic, Jayant Narlikar, director of the Inter-University Centre for Astronomy and Astrophysics in Pune, India.

In the face of such puzzles, Narlikar and others are waiting for much more empirical data from better radio telescopes. "At the moment, I wouldn't like to bet on any particular hypothesis," he said. ◆

To probe further

Classic texts include *Radio Astronomy*, by J. D. Kraus, published by McGraw-Hill in New York most recently in 1986; and *Galactic and Extragalactic Radio-Astronomy*, edited by G. L. Verschuur and K. I. Kellerman, the most recent edition of which was published in 1988 by Springer-Verlag. *Synthesis Imaging in Radio Astronomy* is a collection of lectures from the third NRAO Synthesis Imaging Summer School, held in June 1988. The volume is available from the Astronomical Society of the Pacific in San Francisco; 415-337-1100. *Interferometry and Synthesis in Radio Astronomy*, by Richard Thompson and James W. Moran, was published by John Wiley and Sons, New York, in 1986.

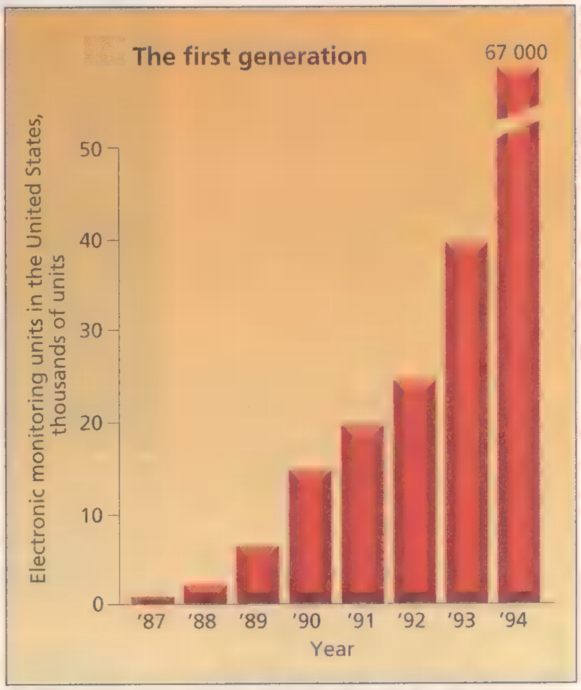
"Millimeter and Submillimeter Wavelength Radio Astronomy," by John M. Payne, was published in the July 1989 *Proceedings of the IEEE* (Vol. 77, pp. 993–1017). The May 1994 edition of *Proceedings* (Vol. 82, pp. 629–828) was a special one on radio telescopes. For a copy, contact the IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331.

Public safety could be improved and incarceration costs cut if new electronic monitoring schemes were put into effect

KEEPING TABS ON CRIMINALS

IN THE UNITED STATES LAST YEAR, there were 1.4 million offenders in prison—twice as many as there were 10 years ago—and another four million out on parole or probation. Criminal justice costs have kept pace: they now come to some US $90 billion a year, about a third as much as the bill for national defense.

Yet bulging law enforcement budgets have made little dent in crime and none, it would seem, in the fears of law-abiding taxpayers. Public safety has become the No. 1 concern of city and suburban residents, according to many recent polls. Technology could do more in their defense, an especially hopeful area being the electronic monitoring of the movements of victimizers.



U.S. NATIONAL INSTITUTE OF JUSTICE; *JOURNAL OF OFFENDER MONITORING*

▲ Offenders who wear electronic monitoring units [redacted] be kept under the equivalent of house arrest. The first generation of these devices [redacted] introduced in the United States in 1986, and their use has climbed steadily.

Present monitoring systems help to keep tens of thousands of offenders under house arrest in the United States, but their scope is limited. They tune in to a transmitting bracelet worn by everyone under their surveillance, but are tuned out by anyone who walks outside the range allowed. Proposals both for upgrades and for a second and even third generation of system architecture exist, and some are highly practical, in that they would build on existing technology and public infrastructure. In fact, if the issues were technology and time alone, comprehensive tracking systems could be installed in several years. Some could even keep stalkers at bay, a growing threat given strident publicity by the O.J. Simpson case.

The world of crime is not the only possible sphere of use for electronic monitoring by tags. Other applications are being contemplated, and some are in hand. The systems could check up on medical patients with, say, heart trouble or Alzheimer's disease, and find where wounded soldiers lie on a battlefield. Keeping track of personnel, vehicles, and inventory, as well as providing security on college campuses, are related applications being pursued.

As the chart above indicates, present offender-

JOSEPH HOSHEN
AT&T Bell Laboratories

JIM SENNOTT
Bradley University

MAX WINKLER
Colorado Department of Corrections

PHOTOS: ■ INC.

◀▼ **Present-day monitoring units—called bracelets, although in fact they fit around an ankle—keep an offender under a kind of house arrest. Each unit contains a battery and transmitter that emits RF signals at regular intervals, as does this product from BI Inc., Boulder, Colo. A receiver connected to a telephone line in the house notifies a central monitoring station when the bracelet's radio transmission is broken or reestablished—a simple means of verifying an offender's presence in or absence from the short-range surveillance area.**

tracking systems have been in use for less than a decade. Some 67 000 such systems are currently being applied by the U.S. criminal justice system. These home detention and curfew systems, to give them their formal name, comprise a transmitter, a simple telephone modem, and a central receiving station. The transmitter is attached to an offender's ankle or wrist and sends periodic RF signals to the modem. Once the transmitter leaves a 45-meter range (usually meaning the wearer has left a residence), the modem sends an alert over the phone lines to the central station.

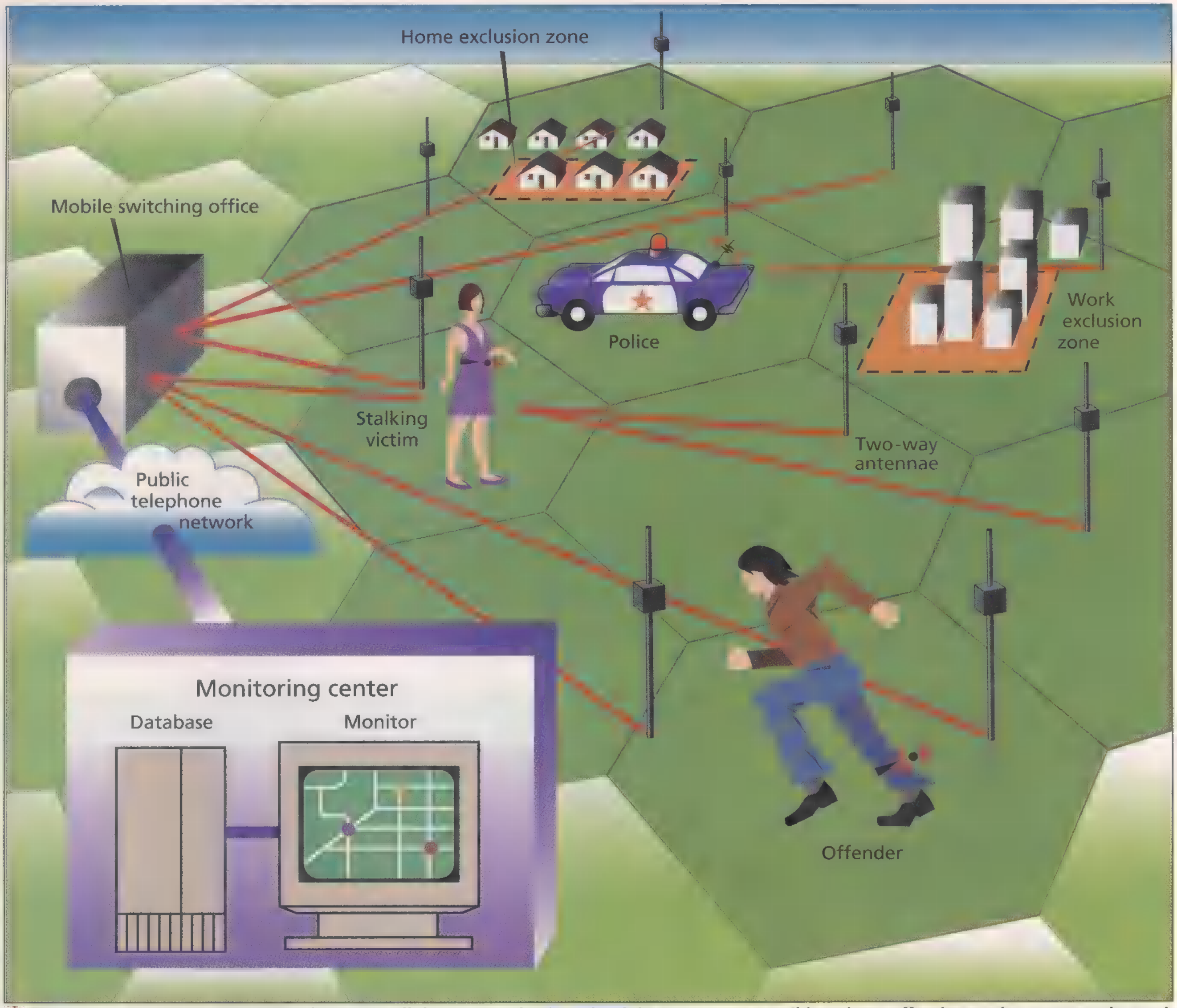
Not yet perfect

Although increasingly accepted, the first wave of home-arrest systems has many shortcomings. For starters, once an offender leaves the monitored residence, it is impossible to monitor his or her movements electronically because of the limited tracking range. Periodic checks on subjects at their work sites and therapy groups are made by a probation or parole officer, but do not account for an individual's whereabouts at other times. The officer's productivity also suffers from the time and travel needed to monitor clients in the field.

Proposed second-generation systems, on the other hand, would track the location of offenders nearly continuously and over wide areas. These expanded powers would help parole and probation officers do a more thorough job of monitoring their clients. It has even been suggested that these systems could in effect replace prison for certain offenders. (The goal would be to save taxpayer money.) But the systems can do little to stop an offender from removing or wrecking the monitoring device and fleeing justice, perhaps to commit more crimes. For fear of offenders on the loose, many people might object to a greater use of merely passive tracking systems.

In some eyes, a true "electronic incarceration" would involve active restraints, such as a remotely applied zap of electricity, for better control of an offender's behavior. If a third-generation system could be devised along these lines and operated reliably, it could embrace all types of offenders, including violent types, and might diminish the need for prisons and jails. First, though, some serious legal and social issues must be addressed for both second- and especially third-generation systems [see "Legal

JEFF BARCAN



▲ Thanks to advances in such technologies as cellular communications, it might soon prove possible to keep offenders under constant electronic surveillance over large tracts of territory. Here, each cell is perhaps 10 km² in area and equipped with an antenna, and everyone and everything being monitored is equipped with a locator unit. Signals transmitted by an offender's locator would be picked up by three or more antenna/processor units and relayed through telephone lines to a monitoring center. There the signals would be processed to yield the latest position coordinates of whoever is on the move. In stalking scenarios, the whereabouts of patrol cars and victims might also be monitored. Whenever a stalker violated a monitoring directive and entered an exclusion zone, such as a victim's home or work area, everyone involved could be notified automatically, including the nearest patrol car. The system could also determine if the victim was being pursued anywhere in the area being watched.

barriers to electronic prisons," p. 32].

Though no second-generation system as yet exists for checking up on miscreants, all of its components are at hand. What is needed is to integrate the elements into a dependable wide-area offender-monitoring system.

Tracking projects

Last October, the National Institute of Justice awarded $410 000 to Westinghouse Corp., Pittsburgh, to develop a prototype second-generation system. It was the first time the U.S. government had supported such an endeavor. Testing will be started in 12 to 18 months' time in downtown Pittsburgh. Locator units attached to subjects will put out 1 W. Locations will be derived from time-of-arrival calculations at several receiving sites within an area of 1 km². The system will use spread spectrum operating in the RF band of 902–928 MHz to pick up the offenders' whereabouts. The goal is for the transmitter battery to last six months.

Other systems being developed for other purposes may also be of use in monitoring offenders. One is an RF tracking system for university campuses, meant to make them safer. Developed by Motorola Inc.'s Diversified Technologies Division, Scottsdale, Ariz., the system can handle 60 000 registered users. Each user is equipped with a pager-sized personal alarm and when threatened, the wearer may generate an alert by pushing a button. A network of receivers scattered throughout the campus picks up the signal, whose arrival time and strength are used to determine its point of origin. This location is displayed on a map at a central facility, and when it appears, a dispatcher notifies the police.

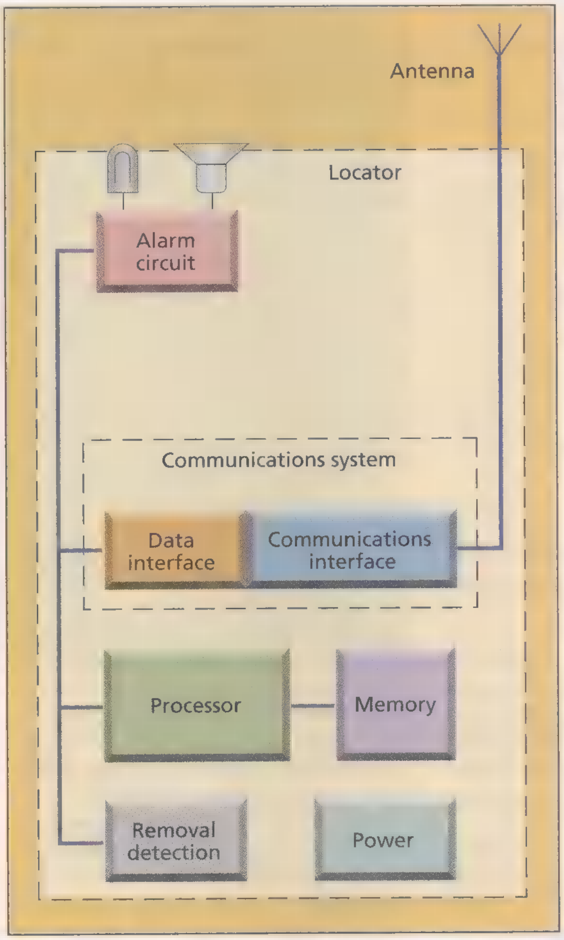
Motorola plans system trials at Arizona State University at Tempe sometime before 1996. In this application, unlike offender monitoring, battery life is not a key design concern, since a signal from the unit is emitted only when an alarm is sounded. Meanwhile, another division of the company is examining a prototype for prison applications.

One of the systems for tracking vehicles (often to thwart car thieves) comes from Air Touch Teletrac, Garden Grove, Calif. Several cities have already put it to use, including Chicago and Los Angeles. It is also a spread-spectrum system, and uses triangulation, based on a signal's times of arrival at various receivers, to locate a vehicle. The mobile locators and the receivers for the system were both developed by Tadiran Ltd., Israel. The locators may be polled by the central station or can automatically send alarms to signal such criminal activity as an automotive break-in.

In the polling mode, the system can continuously locate the positions of vehicles in a fleet. In the alarm mode, it is used mostly as an anti-theft device. Because of its continuous tracking ability, it operates much like a second-generation offender system. The big difference is that with vehicles, the unit's size and power consumption are trivial issues.

Medical applications may also foster second-generation systems. An early step is the Trauma Care Information Management System (TCIMS). The wireless communications architecture to be developed in this project would enable monitors worn by soldiers to transmit their vital signs over wide areas. The signals could speed the rescue and improve the outcome for any user wounded in battle.

Announced by the Advanced Research Projects Agency (ARPA) in December 1993, this project, part of the Technology Reinvestment Program, is under development by a consortium of universities, medical experts, and corporations, including AT&T Corp. and Rockwell International Corp. Architecturally it is similar to the proposed offender-tracking system. It would also include a medical and resource database that interconnects with trauma-monitoring units through a wireless communication network.



In a second-generation locator, many of the major components are familiar, such as a central processing unit, memory, power, communication system, and antenna. Also included on the locator bus is a removal detection unit that, if any tampering occurs, could send an alert on an emergency channel kept free of traffic. An onboard alarm circuit could alert an offender to a violation—intentional or otherwise—so he could remedy matters by reentering the permitted zone or quitting a prohibited one.

Tracking technology

In second-generation systems for checking up on known wrongdoers, a critical need is the capacity to report on people's position both inside and outside buildings. Updates at regular intervals from just about any locale are the goal. (Continuous updates would be a useless drain on the battery of the bracelet transmitter.) Strictly supervisory signals should be sent to the bracelet locator, too, for management purposes. These signals would be proof of reception quality and system status, and would convey commands like "change frequency band" or "download new parameters." The system must also reckon with interference, jamming, and attempts on offenders' parts to disguise their identity or position by electronic spoofing.

Position-fixing can be done in two ways. One method uses the locator as a receiver, to process inputs from many sources, such as Global Positioning System (GPS) satellites, with position data sent back to a monitoring station through a return data link. The second uses the locator as a transmitter, whose signal is used by several remote receiving sites to calculate its place of origin by measuring the phase, time of arrival, roundtrip range, or bearing angle of the signal.

In the first approach, the locator makes its own time-of-arrival or phase measurements, perhaps using GPS or Loran-C readings. Both these navigation systems have their shortcomings, and neither can pick up signals from inside buildings. And although GPS and Loran-C receivers have become highly miniaturized, they still use up more power than the locator power budget can readily allow.

One way around the reception difficulty is the Position, Information, Navigation System (PINS), with the locator measuring relative phase angles of commercial broadcast 19-kHz FM0 subcarri-

Defining terms

Offender Electronic Monitoring: a procedure that electronically tracks the activities of an offender, often simply checking to see if the person is at home in a kind of house arrest.

Monitoring directive: a rule that governs what an offender can or cannot do under his or her electronic monitoring schedule; it might include the times of day the offender has to stay at home and when he or she may go to work. Deviations from the directive are considered monitoring violations.

First-generation systems: systems in existence today that electronically monitor an offender at one location; also sometimes referred to as home arrest, home detention, and curfew systems.

Second-generation systems: systems that would help track an offender nearly continuously over a wide geographical area, anywhere from a small municipality to an entire country in extent; also known as wide-area electronic monitoring systems.

Third-generation systems: systems similar to second-generation systems in the range of coverage, but perhaps also including some punitive measure. If an offender violated monitoring directives, for example, the tracking unit attached to the offender could generate an electric shock to subdue him or her. Also known as electronic incarceration systems.

ers. Position calibration is done at monitoring sites that also collect phase observations. In one estimate, if updates in real time were not vital, an FM system for tracking persons on probation could be built in mere months. Or so says the Terrapin subsidiary of KOR Electronics Corp., Garden Grove, Calif. A user's position tracks would be stored on a locator worn on the person and would be uploaded to a monitoring center once a day, in order to check compliance with the parolee's monitoring directive.

More typical of possible systems are those based upon actively transmitting locators, such as the previously mentioned Westinghouse and Motorola systems [see table at right].

At Sandia National Laboratories, Albuquerque, N.M., transponders the size of credit cards that require very little power have been developed. The objective is a precise on-demand method. In Sandia's two-way system, every tagged item is paged to transmit a spread-spectrum code. Three or more receiver sites busily decode and time-stamp signal arrival times and data packets before passing them on to a central monitoring station. The estimated distance between receiver grid sites is approximately 8 km.

Though in general prototype systems pin down locations by means of time-of-arrival measurements, KSI Inc. has gone a different route. The Annandale, Va., company has developed phased-array antenna systems and digital signal-processor algorithms for the precise measurement of bearing angles. Two or more bearings are used to triangulate position.

This triangulation technology could also be applied to locating the origins of 911 emergency telephone calls and of users of personal communication services and two-way digital paging devices. The Federal Communications Commission, Washington, D.C., is even now considering rules that would require cellular operators to include 911 call location features, to which the KSI system would be applied.

Whichever approach is adopted, the related issues of path loss and battery life must be confronted. The paging and cellular phone systems yield some estimation of expected levels of transmission loss, but an offender's locator must transmit packets repeatedly at short intervals over weeks or months. Because anti-spoofing and anti-interference features would also be desired, a new signal format might be needed.

What might such a format look like? Preliminary calculations suggest a peak power level of 10 mW, with a 1-percent duty factor. Data packets sent by the locator would be 25 to 50 bits long and be received up to 10 km away. Data would be modulated on pseudorandom codes, having a much higher time-bandwidth product than that proposed for personal communications systems.

Follow that man/car/you name it: some of today's tracking systems

System and manufacturer	Position-fixing technique	Locator-to-station link	Station-to-locator link
Position, Information, Navigation System (PINS) Terrapin Corp. Garden Grove, Calif.	Relative phase measurement of FM broadcast subcarriers	A radio link	FM broadcast subcarrier may be used
Personal Alarm Communicator Motorola Inc. Scottsdale, Ariz.	Relative signal arrival times and amplitude at remote stations	Spread-spectrum 900 MHZ	None
Offender Monitor Westinghouse Corp. Pittsburgh	As above, minus signal amplitude	Spread-spectrum 900 MHZ	None
Locator Tag Sandia National Laboratories Albuquerque, N.M.	As above, minus signal amplitude	Spread-spectrum at microwave frequency	Spread-spectrum at microwave frequency
Direction Finding and Localization System (DFLS) KSI Inc. Annandale, Va.	Angular measurement from two or more stations	Cellular, personal communication system (PCS), or two-way paging	Cellular, personal communication system (PCS), or two-way paging

For greater immunity to spoofing and jamming, the pseudorandom waveforms could be dynamically and uniquely assigned to individual locators. Receiving stations would house low-cost programmable correlator banks based on very large-scale ICs, with the process of acquiring and re-acquiring data being assisted by the supervisory channel. Assuming one update every 100th second, a 0.1-kg battery could hold out for 60 days, or longer if adaptable control were used to, say, lower the frequency of updates during the hours of sleep.

A system view

NATIONWIDE, THE EXISTING U.S. wireless infrastructure could be the foundation for a system-level architecture for keeping tabs on parolees and also for detecting stalkers. It might include cellular telephony, two-way paging, and data-packet networks.

In this setup, those sentenced to electronic supervision would wear an RF monitoring locator on a wrist or ankle, just as they do today. These bracelets would look much like the first-generation house arrest units, being about the size of a pager. In addition, they would resist tampering and detect tampering attempts.

Internally, though, the second-generation units would be quite different from their predecessors. They would be small computers exchanging data packets by radio with a central database system. The database would poll offenders' locators by sending them data packets, each of which would contain an identification number unique to the offender. Reading these packets, the locator would pick those that matched its ID. This polling technique would, for one thing, improve the efficiency of the RF channel. For example, communicating with different offenders at different rates would become possible, and after all, not all offenders need the same level of monitoring.

Furthermore, the system could raise the polling rate dynamically as soon as an offender transgressed any directives. As soon as the device received a poll, it would send the database an acknowledgment, which would also, via triangulation, cue the tracking system as to its origin .

The center of this system would be the database, storing information on where the offender should be at any given time. For example, the database could specify the offender's home, workplace, and the commute between them, and the times at which the offender should be found in each. From the database's perspective, these locations would be defined as polygon coordinates. The subject could be required to stay inside the polygon or stay outside it. The database would compare the observed coordinates of the supervisee with the stored location for a given time interval.

Computerized database systems would control communication with the locators and maintain pertinent information on the individuals being tracked. They would depend even more heavily on RF transmission than their forerunners did, so that unauthorized access to the transmission data or, worse still, transmission spoofing,

would have to be prevented.

The system should also present a miscreant's location in visual terms in real time on a city map. It should produce reports on the system's performance and individual offender activities. Its integrity would have to be such that reports on an individual could be admitted as evidence in a court of law (the person accused could even benefit if it proved his or her absence from the scene of a crime).

Stalking scenario

A second-generation tracking system might be applied in many circumstances, including drug dealing and the stalking of persons perceived to be enemies.

While the statistics available are neither accurate nor detailed, stalking incidents are clearly widespread. According to a survey by the U.S. National Institute of Justice, 94 percent of the responding police agencies indicated an awareness of the practice in their jurisdiction.

In the case of stalkers, some locations defined in the database, such as an ex-spouse's house, could be those from which the offender is excluded. For child molesters, schools and parks could be off limits. Exclusion zones may also be needed for RF "dead spots" that cannot adequately be covered by the system because of such factors as geography.

Nonetheless, unless there is very wide area coverage, exclusion zones alone are insufficient. The database must also define the boundaries of areas in which a stalker is permitted. Otherwise, a stalker could leave a surveillance range to disarm his locator and then, undetected, reenter an exclusion zone to attack his prey.

The database could track the stalker, the prey, and mobile police units by the locators attached to everyone. If a zone violation occurred, or if paths crossed serendipitously, the system would automatically alert both the quarry and the nearest mobile police units.

The drug scene

Nearly 60 percent of all Federal prisoners are now drug felons. Their average prison terms have increased by 22 percent since 1986, even while the terms of those convicted of violent crimes fell by 30 percent. Federal prison space is scarce, and the tough, inflexible Federal sentencing rules do not allow parole for drug felons. But some judges are protesting this state of affairs.

A wide-area monitoring system might replace prison for those given the minimum sentences now imposed for drug offenses unmarred by violence. Certainly the monitoring of drug offenders would hinder any further drug transactions. Drug dealers could develop new delivery scenarios, but the tracking system would make this less convenient.

Further, to counter possible drug abuse by some offenders, the locator could be equipped with a broad-based tool for monitoring vital signs such as pulse rate and blood pressure. The base station computer would analyze vital signs in real time for patterns indicative of drug abuse. Any such finding could be verified by the system's automatic dispatch of someone from the corrections department to wherever the offender was. Coincidentally, ARPA's trauma care consortium is developing a module for monitoring vital signs remotely.

System limitations

The recent case of convicted rapist Christopher Freed shows why the current monitoring system needs improvement. Freed, who had confessed to seven rapes, was convicted on one charge and sentenced to 18 years in a New Mexico prison. Another 18 months were tacked on for his attempted rape of a woman while he was on a work detail program.

Last Sept. 7, Freed was released on parole for good behavior after serving 10 years. One condition was that, to verify his night curfew, he wear a first-generation "home arrest unit"—the same unit as shown on p. 27. For a few days this arrangement worked quite well. One morning after night curfew, however, Freed fled, driving a brown Nissan Stanza.

Since first-generation systems do not monitor offenders when they are away from home, many hours passed before anyone realized that he had violated the conditions of his parole. After 10 days of exhaustive search—and much fear among the state's population—Freed was captured in Colorado Springs, Colo.

Two questions come to mind. Would a second-generation system have worked in this case? If not, could a third-generation monitoring *and restraining* system have prevented Freed from violating his parole conditions and so assured the public of greater security?

It seems that in Freed's case a second-generation system would have been a distinct improvement. In a matter of minutes it would have spotted a deviation from parole directives (which could be specified in more detail) and determined Freed's location. Assuming that police procedures evolve in step with the new tracking technology, Freed could have been detained quickly.

Alternatively, the second-generation system might have prevented Freed from absconding at all by immediately notifying him of his parole violation. Freed might then have dropped plans to flee since he no longer had an entire day's head start.

A hypothetical third-generation system might first send Freed an audible alarm or other warning signal. If this had no effect on Freed's behavior (supposing that any effect could be measured), the system would try to stop him with some kind of remote restraint. But suppose the system determined that Freed was in a moving vehicle. Would any administrator risk hurting bystanders by remotely zapping a moving target? Such an issue poses a problem for the third-generation systems.

A third-generation system would also require a much higher level of confidence in its electronic integrity than a second-generation system, because the penalty for making an error would be much greater. (A false alarm, for example, in the form of an audible supervisory signal sent by a second-generation system to a parolee, would have a minimum of adverse consequences.)

What next?

Current estimates of many of the parameters of a second-generation system are only rough and not always reliable. This is true of location accuracy, RF building penetration, battery power requirements, and parameter tradeoffs. Yet accurate data are critical to system success. How should the alternatives be explored? A consortium of private companies, national laboratories, universities, and end-users such as Federal, state and local correction entities may be the best approach.

The consortium could study: the feasibility of such systems; communication and interface standards; legal changes that might be needed before there could be a system go-ahead; human aspects (such as which types of offenders would be candidates for these systems); and ethics and social impacts and safeguards. Also to be examined are economic considerations such as the dollar cost to society, in comparison with outlays for the existing prison system, and the size of the market—basically, how many offenders would qualify as system users. A demonstration system could be developed and tried out on real offenders.

The consortium would function for only two to three years and disband. Then companies would be free to compete with each other, building their own products using the experience gained by the consortium.

In a broader context, the public and U.S. Congress should be made aware that technology can contribute to the solutions in criminal justice. A meager $3 million to $5 million annually is allocated through the National Institute of Justice for science and technology projects. Twenty crime bills over the past 40 years

Legal barriers to electronic prisons

In the late 1980s, it was predicted that the first-generation electronic system for monitoring offenders would be challenged in a Federal court, maybe all the way up to the Supreme Court, on the grounds that it infringed upon rights to privacy. Such a challenge has not occurred, probably because any such suit would overturn, not a conviction, but only the sentence handed down in a case. The offender would then be re-sentenced, possibly to some punishment more unpleasant than house arrest.

The second-generation system of near-continuous monitoring may prove a bigger legal challenge because it invades all aspects of the offender's life. The database in a first-generation system is limited only to violations (for example, not being at home when required to be there). But in a second-generation scenario, a complete log on the offender would be compiled, including activities that comply with parole or probation conditions but for preference are kept private. At the very least, strict judicial supervision of access to the database would be a prerequisite.

Although society may not object to the offender choosing electronic monitoring voluntarily, agreement to use it for certain violent crimes as an alternative to a sentence behind bars is unlikely. (For instance, a sex offender in the United States was recently denied the option of voluntary castration as an alternative to imprisonment.)

The possible use of the system to tightly control lesser offenders would probably raise the odds of legal challenges to the monitorlng system. In those cases, the alternative sentencing may be perceived as better. Obviously, the legislative and judicial branches of government would have to develop consistent guidelines for sentencing someone to electronic monitoring, to avert other constitutional challenges.

Third-generation systems, those with some form of remotely activated restraint, could well give rise to an even wider range of challenges. In addition to the issue of privacy, possible challenges involve the 8th amendment (cruel and unusual punishment), 5th amendment (due process), the 14th amendment (due process and equal protection of the law), and the 6th and 13th amendments (issues also related to due process, such as confronting witnesses, the right to counsel and involuntary servitude without being duly convicted). The success of any such challenges will depend on the composition of the courts, the legal and judicial safeguard integrated into the system and the specifics of the particular cases.

The third-generation system may be implemented as a strictly voluntary preference for its supervision rather than incarceration, and as a way to help the offender learn self-restraint. If this is done within court guidelines, the door will be open to the use of the system under strict judicial control for therapeutic purposes without compromising either protection against cruel and unusual punishment or rights for due process and equal protection.

But any form of involuntary use of such a system, outside the control of dangerous behavior and escape attempts spotted by law enforcement authorities, could be disastrous. It could open the floodgates to constitutional challenges by offenders and by civil libertarians and to lawsuits by innocent bystanders.

—Dan Miller

Dan Miller earned a doctorate in criminology from the University of California, Berkeley, in 1980. He is now in private business in Wheaton, Ill.

have ignored technology support for crime and punishment. Congress' 1994 crime bill was no exception. The question is: how much worse will things get before they get better? ◆

Acknowledgments

John Browning from Sandia National Laboratories was an indispensable contributor to this article. Helpful inputs also came from Rickie Currens of Motorola Corp.; George Drake of the New Mexico Department of Corrections, Diversified Technologies; James Gover, an IEEE Competitiveness Fellow with the U.S. Department of Commerce; Eliezer Haberman of Tadiran Ltd.; Charles J. Hinkle Jr. of KSI Inc.; John Murphy of Westinghouse Corp.; Marc Renzuma of Kutztown University; Louis Greenbaum of Terrapin Corp.; and Richard M. Satava of the U. S. Army Medical Corps.

To probe further

The Journal of Offender Monitoring presents correctional studies of the application of electronic monitoring to offenders. It also discusses legal issues and the current technology and equipment of electronic monitoring.

Additional information on electronic monitoring studies can be found in: *Intermediate Sanctions, Section I*, edited by W. L. Selke, and J. O. Smykla, October 1994 (Anderson Publishing, Cincinnati, Ohio). A review by M. Winkler on the future direction of electronic monitoring technology (the three generations) is presented in an article titled "Walking Prisons, the Developing Technology of Electronic Control" in the July/August 1993 issue of the *Futurist*, p. 34.

Information on stalking and its prevention may be obtained from the U.S. National Institute of Justice, Report NJC 144477, "Project to Develop a Model Anti-Stalking Code for States." An article titled "A High Performance Position Tracker for Embedded Paging, Cellular Telephone and Law Enforcement Application," by J. Sennott and R. Matusiak, was presented in 1992's *IEEE Position Location and Navigation Symposium* proceedings, p. 96.

A review of GPS and Loran radio positioning systems appeared in *IEEE Spectrum*, p. 36, of December 1993. Recent information on the application of electronic security technology by security agencies and law enforcement is available from the proceedings of the 28th IEEE Annual International Carnahan Conference on Security Technology, which was held last October in Albuquerque, N.M.

An analysis of the public acceptance of alternatives to incarceration has been completed by Angela R. Gover, who works for the Governor's Office in Maryland. The survey data are published in the September 1993 *Forum of the Justice Research and Statistics Association*.

About the authors

Joseph Hoshen (M) is a member of the technical staff at AT&T Bell Laboratories, Naperville, Ill., where he has been active in data communication, local-area networks, backup systems, project tracking, and software updates. From 1971 to 1980, Hoshen was an associate research scientist at the University of Michigan.

Jim Sennott (M) is professor of electrical and computer engineering at Bradley University, Peoria, Ill., directing navigation and surveillance research with an emphasis on GPS and multiple-access communications. Prior experience includes Howard University and Mitre Corp.

Max Winkler has been a parole officer for the State of Colorado since 1986, having been a correctional case manager for it during 1980–86. He is also Research Fellow at the Independence Institute, Golden, Colo. He received an M.A. in sociology from the University of Colorado in 1976.

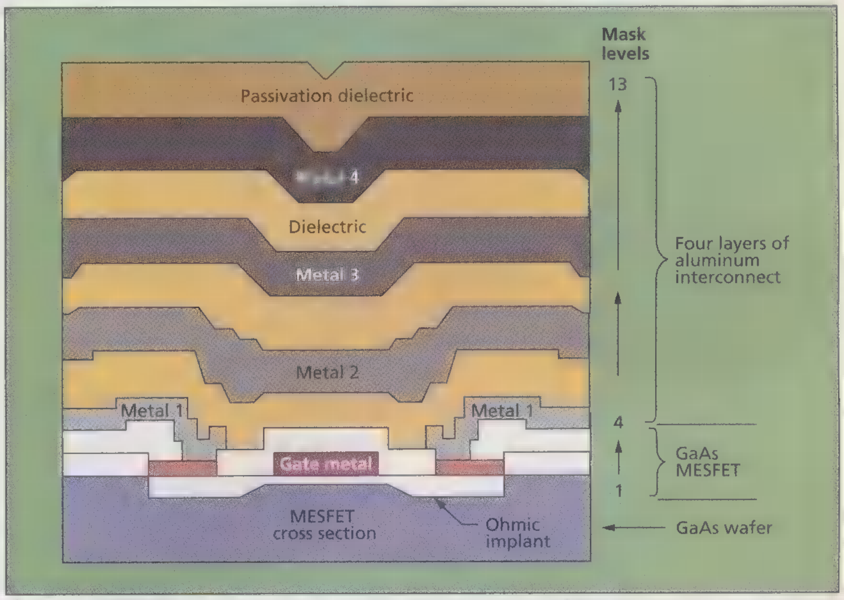
Very large-scale ICs, based on a compound material yet surprisingly simple to make, are ready for top-speed system design

GALLIUM ARSENIDE JOINS THE GIANTS

GALLIUM ARSENIDE has enjoyed a unique position in the electronics industry for more than 25 years. Yet in all this time, the unusual properties it shares with other III–V compounds have been applied only to rather simple circuits. Examples are solid-state lasers and emitters of visible or near-infrared light, as well as radio frequency and microwave amplifiers. Each requires high performance, but none needs more than a few transistors and diodes per chip.

Breaking with this past simplicity, GaAs is emerging as the starting material for integrated circuits with one million or more transistors per chip. The technology today is firmly in the domain of high-performance, very large-scale integration (VLSI), with chip clock rates hitting 100 MHz and up. And to cap everything, the manufacturing cost is reasonable.

GaAs VLSI technology got under way in earnest less than eight years ago and in short order has shot up spectacularly in complexity, or number of transistors per chip. Because the transistors in GaAs VLSI switch very swiftly, logic gates based on the devices impose much less delay on signals than does the silicon variety. The VLSI performance that results is either impossible or difficult to attain with silicon. For example, the shortest silicon CMOS gate delay is about 150 ps versus 70 ps for GaAs, both in 0.5-μm technology. As for commercial success, GaAs VLSI has excellent prospects, being the offspring of a very simple process married to silicon IC manufacturing technology and equipment.



▲ **GaAs MESFETs are similar in construction to silicon CMOS devices, but somewhat simpler. While CMOS requires six or more mask levels to make the n- and p-channel devices, GaAs MESFETs use only n-channel devices that can be made with only four mask levels. The wiring levels of the two technologies are identical for all practical purposes.**

Present forms of GaAs VLSI are higher-performing versions of silicon VLSI. The GaAs transistors just speed up the same old IC concepts. Still in the future are truly novel chips, incorporating devices like optical emitters or microwave amplifiers that can be built only in GaAs III–V compounds.

Compare and contrast

VLSI manufacturing can be characterized as the art of layering a chip with lots of transistors having reasonably similar characteristics and connecting them on that same chip without shorts or opens. By this stage, "lots of transistors" can mean several million, and "connecting them" entails hundreds of meters of approximately 1-μm "wires" separated by spaces of 1 μm or less.

As luck would have it, GaAs VLSI did not have to reinvent this art. The bulk of the production process is copied directly from silicon and uses the same equipment. In fact, GaAs VLSI manufacturing has more in common with silicon CMOS technology than with earlier GaAs [see figure above]. A key difference, however, exists between the two VLSI processes: fewer steps are needed to produce GaAs circuitry. Granted, the

IRA DEYHIMY
Vitesse Semiconductor Corp.

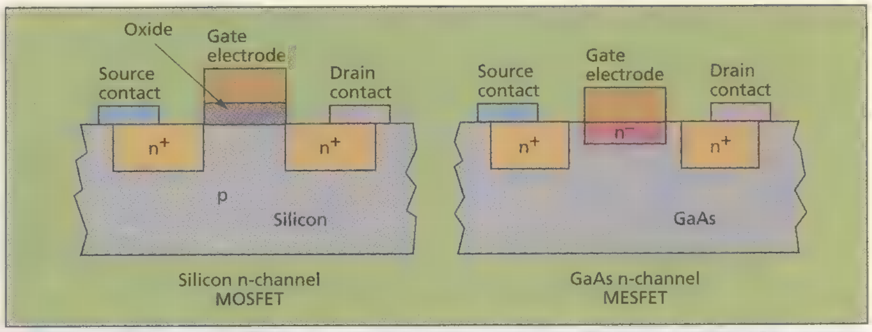
0018-9235/95/$4.00©1995 IEEE

fabrication of the wiring levels, which forms the bulk of the process, is identical for both technologies. But only four mask levels are needed to define the GaAs transistor compared with six for the silicon device. The simplification to some extent offsets the greater expense of the GaAs starting wafers.

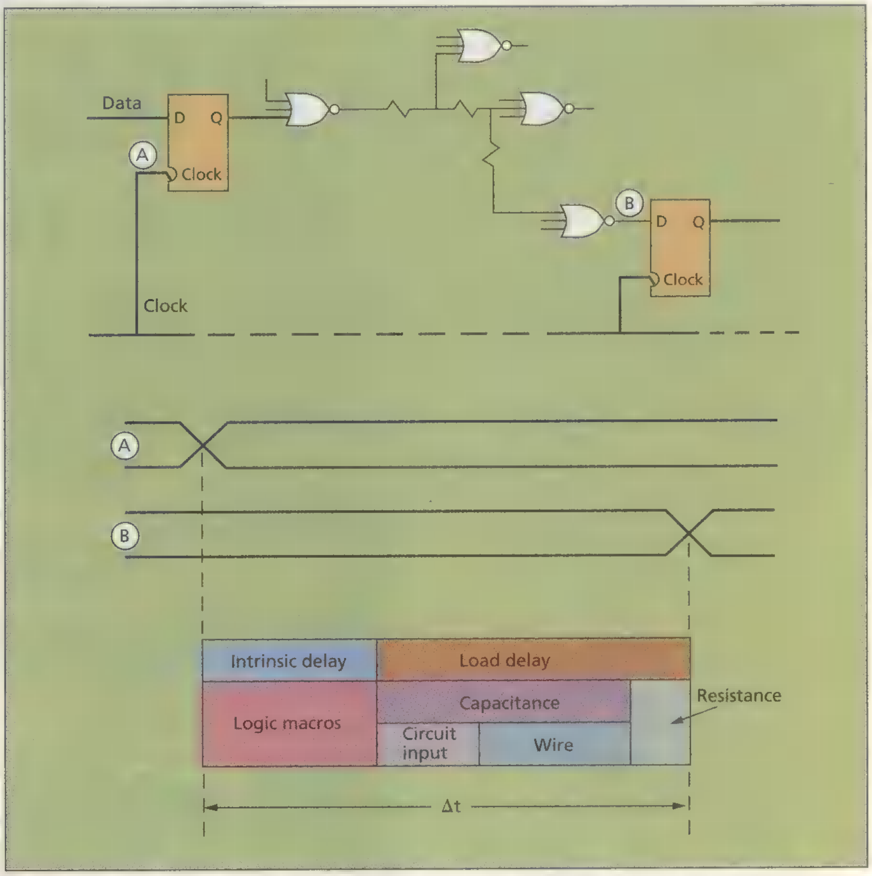
Both these VLSI transistors are the offspring of ion implantation: ion beams impregnate the starting semiconductor material with dopants. The devices are also alike in being field-effect transistors: current flows between their source and drain whenever a voltage is applied to their control terminal (gate), generating an electric field between the gate and the channel. But in crucial ways the two differ [see top right figure].

First, the conducting channel (n-channel) is created in the GaAs device by a separate implantation step, whereas in the silicon device, the n-channel is created electrically, by "inversion" of the p-type material. Second, in the GaAs device, the electrons forming the current pass a little beneath the semiconductor surface; consequently, the electron dynamic behavior of the buried-channel device is ruled by the semiconductor's bulk properties. In the silicon device, the electrons stream across the surface of the semiconductor and behave in accordance with surface properties.

A third influential difference is gate insulation, or its absence. In the silicon device, the gate is separated from the semiconductor surface by a thin oxide layer, producing an insulated-gate device. In the GaAs transistor, the gate electrode contacts the semiconductor surface directly, forming a diode between this terminal and the channel.



Differences between silicon and GaAs transistors include the channel formation and the gate insulation. In GaAs the channel is implanted, in contrast to silicon where the channel is formed by inversion. Further, the gate of the GaAs device makes direct contact with the channel, while in silicon the two are separated by a thin oxide layer.



Delay through a logic net, Δt, is the time interval between the rising edges of a signal at the inputs of the first and last element in the net.

Performance is all

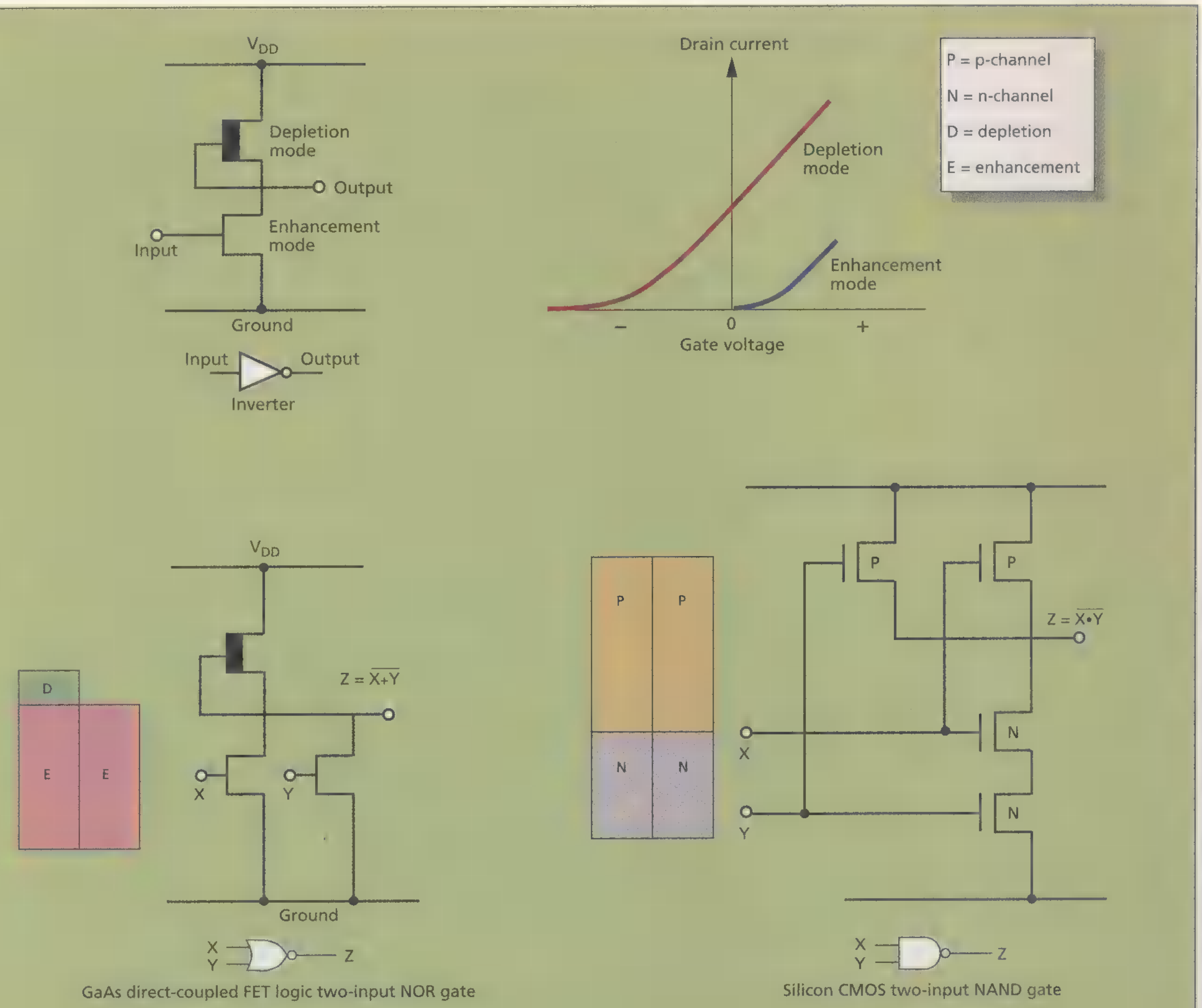
The whole reason for using the III–V compound to build VLSI is to get the highest level of performance possible. In some cases GaAs can scale heights of virtuosity otherwise inaccessible. In others, the margin of speed granted by the III–V compound obviates any need for the parallel processing of data, resulting in a less costly logic implementation that uses fewer transistors and occupies less space.

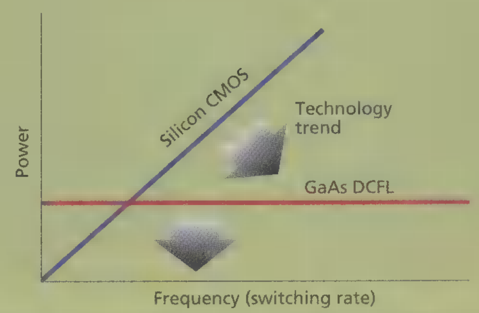
In point of fact, performance means different things in the context of different applications. Thus computation and communication, whose leading edges keep digital chips on the run, so to speak, require rather different things of the technology.

In the computer arena, VLSI performance translates into minimizing signal delay through the chip. After all, such a chip swarms with decision points (or branches) in the logic. At each point, the value of the result of an operation determines what happens next; and the aggregate of these operations, plus their speed, determine the throughput of the system. Put another way, signal delay consists by and large of transistors' switching time, their density on the chip, and (indirectly) any limit on their number per chip.

For most communication applications, in contrast, VLSI performance is measured in terms of bandwidth rather than delay. A communication system's latency (or delay) is generally at the mercy of the communication channel. Because the signal may pass through long optical-fiber cables or be relayed by satellite, for example, the latency of the IC pales in comparison. What counts much more heavily is the highest frequency of which the transistors are capable: the higher, the better. A figure of merit typically used here is the unity–current-gain crossover frequency, which is directly tied to fundamental material properties [see "Material properties of gallium arsenide," p. 36]. In this respect, GaAs transistors can boast three to five times the performance of silicon devices, their peers in gate length and other feature sizes.

Within any VLSI chip, total signal delay sums whatever is due to logic macros (for example, gates and flip-flops) with whatever is due to the capacitance





▲ The GaAs inverter is formed with enhancement- and depletion-mode n-channel FETs [left at top]. The depletion-mode device is always on, while the enhancement-mode device turns on when positive voltage is applied to the input. A fundamental building block of GaAs direct-coupled FET logic is the two-input NOR gate, while that of silicon CMOS is the two-input NAND [middle]. The use of three transistors in the GaAs case, compared with four for silicon CMOS, makes for a more compact logic element. Power dissipated by a silicon CMOS gate is proportional to the frequency of operation, while that dissipated by a GaAs logic element is independent of frequency [right].

and resistance of interconnect wiring. Consider a VLSI circuit containing a network of logic gates and flip-flops [bottom figure, opposite]. Delay in such a net grows more or less linearly with the magnitude of capacitance being charged and discharged. One element here is the total input capacitance of the transistors, which scales with fanout—the number of gates driven. The other is the parasitic capacitance of the interconnect wiring, which is proportional to the length of all the wire in a net.

The delay of this net is the interval between the times at which the signal crosses the logic threshold of the first and last gates in the net. The duration of this interval can be divided into the time the signal takes to make its way through the driving gate or other macro, plus the time the macro's output takes to charge the distributed RC network. (The RC net consists of wiring resistance, wiring capacitance, and capacitance of the driven macros.) Thus, in a well-designed layout—one that minimizes the effect of parasitic capacitance and resistance—more than half the delay is either directly or indirectly due to the transistors.

This outline of the influences on VLSI performance also underscores a further fact: that GaAs ICs outperform CMOS ICs packing in about the same number of devices per unit area. But while GaAs is

Material properties of gallium arsenide

The principal motive for building transistors out of gallium arsenide (instead of the ubiquitous silicon) is speed and more speed—either higher maximum frequency of operation or higher logic switching speed. This outcome is to be expected because of the superior electron dynamics of n-type GaAs.

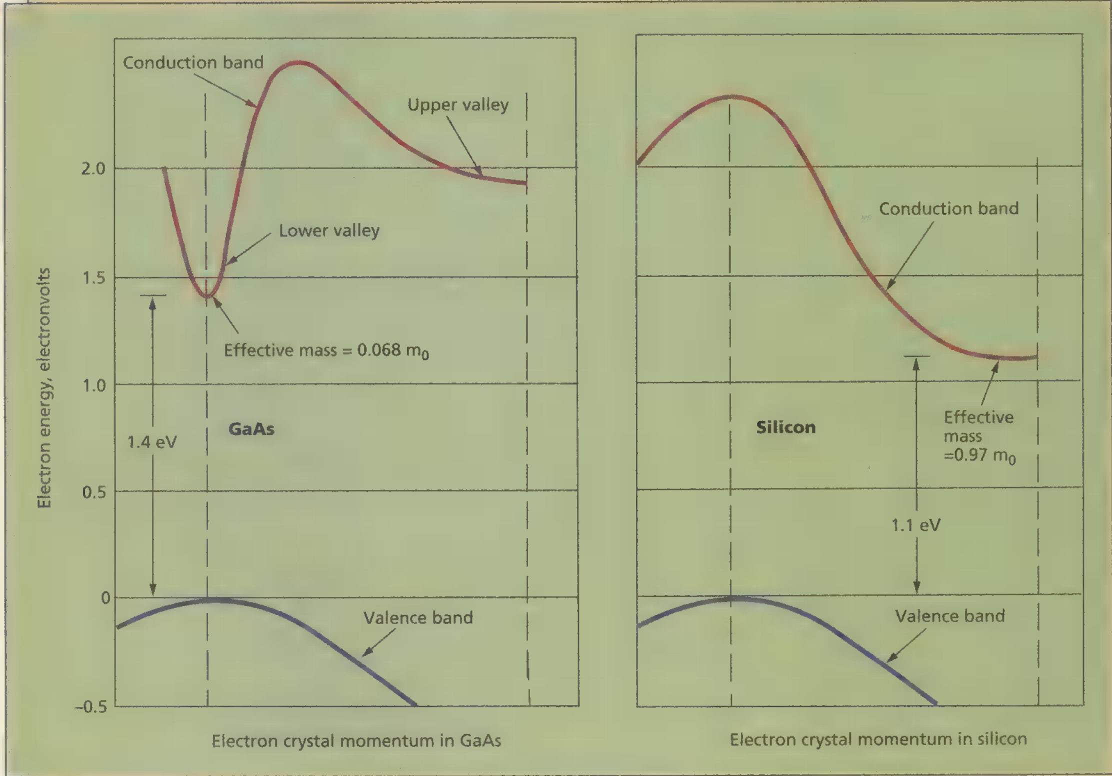
The material's potential for higher-performance transistors was realized soon after the invention of the transistor in 1947 by William Shockley, John Bardeen, and Walter Brattain, and is hardly a new discovery. Early development in solid-state electron devices, however, centered on germanium, then silicon, and not GaAs. The reason? GaAs is a much more difficult material to work with in semiconductor manufacturing.

The physical and chemical properties of GaAs differ from those of silicon [see table opposite]. Silicon is an elemental semiconductor material, whereas GaAs is a binary compound (one atom each of gallium and arsenic). This fact lies at the root of many of the technological obstacles to utilizing the III-V compound in electronic devices.

Silicon is plentiful (sand is SiO_2), while gallium is generally extracted as a by-product of aluminum production from bauxite. Moreover, GaAs material dissociates at the high temperatures needed in the IC manufacturing process unless measures are taken to prevent the disaster. Again, no effective n-type diffusion species is known for GaAs, so that GaAs devices could be constructed only on epitaxial layers until the advent of ion implantation, in use today in all VLSI technologies. Then, too, GaAs has about one-third the thermal conductivity of silicon and about three times its thermal expansion coefficient. (On the other hand, GaAs devices can operate at higher temperatures.) Also, no device-quality oxide, needed for insulated-gate devices (MOSFETs), is known to exist for GaAs.

Clearly, the direct band gap of GaAs is singularly appropriate for optical devices. But the sole benefit of using GaAs for digital ICs accrues from its electron dynamic properties. In equivalently doped n-type GaAs and silicon, the effective mass of the electric charge carriers in GaAs is far less than in silicon. In other words, for a given electric field strength, electrons in GaAs are accelerated to a higher velocity, so that they traverse the transistor channel in less time. For low electric fields, the velocity and field are roughly proportional, with the constant of proportionality being known as mobility.

It so happens that electrons travel faster through n-type GaAs than they do through similarly doped silicon because of the relative shapes of the conduction bands. As the band diagrams at left show, the minimum point of the



unlikely to overtake CMOS in VLSI packing density, the two technologies are converging in this respect.

Top in topology

The logic circuit topology with the attributes desired for GaAs VLSI is adapted not from CMOS but from silicon n-channel MOS technology. It is called direct-coupled FET logic [in middle of figure, p.35]. The most basic logic structure is the inverter, which consists of two n-channel devices, a normally-off and a normally-on one (enhancement- and depletion-mode types, respectively). Only the enhancement-mode device in fact switches; the depletion device is always on. In both GaAs direct-coupled FET logic and silicon n-channel MOS, this general topology is called ratioed logic, since the ratio of the size of the pull-up (depletion) transistor to the size of the pull-down (enhancement) transistor is adjusted in order to balance the currents from these two transistor types.

NOR-based logic is easier to use than NAND-based logic in GaAs. Logic gates with two, three, or more inputs may be built simply by connecting more enhancement-mode devices in parallel. It so happens that several aspects of GaAs direct-coupled FET logic mesh well with the needs of VLSI logic. First, a great many devices fit on a chip, because the logic circuit is very simple, and the material properties of the III–V compound yield small transistors delivering large currents.

Second, the speed, or for that matter, the delay of this circuit type is unaffected by power supply voltages down to about 1 V, meaning that power dissipation can be reduced without degrading perfor-

GaAs conduction band is near the zero point of crystal lattice momentum. For silicon, on the other hand, the conduction-band minimum is at high momentum. Moreover, high electron velocities are implied by the rate with which the GaAs conduction-band energy increases with momentum.

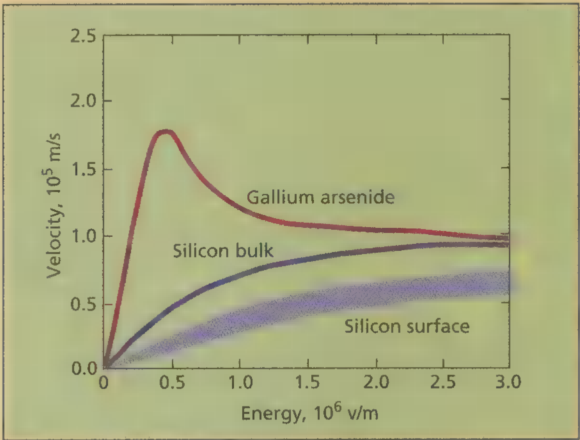
The curvature of the energy versus momentum profiles delineates the effective mass of the electrons traveling through the crystal lattice since the second derivative is proportional to the inverse of the effective mass. For GaAs, the effective mass is 0.068 times the free space mass of an electron, while for silicon, the factor is 0.97. This is the reason one sometimes hears of electrons in silicon being "heavier."

Still other interesting features may be inferred from these band diagrams. First, the valence bands for silicon and GaAs are quite similar in shape, implying similar p-type mobility in both materials and hence no speed advantage in p-channel GaAs transistors. And second, there is a so-called upper valley in the GaAs conduction band whose minimum is near the same momentum as the minimum of the silicon conduction band. This upper valley supplies the compound semiconductor with additional electronic properties.

To review these, consider a graph of the relationship between carrier velocity and electric field [above right], often used to show the differences in electronic properties of GaAs and silicon. The slope of the curve in the nonsaturated regime defines the mobility. Note that at low electric fields, the carrier velocity in n-channel GaAs is much higher than in equivalently doped silicon. This follows from the previous energy band discussion and corresponds to carriers being excited near the minimum of the main conduction band where the slope is large. Notice, too, that at high electric fields, the velocities become saturated and roughly similar. Referring back to the GaAs band diagram, the high-mobility regime corresponds to carrier excitation in the lower valley. As the electric field is increased, electrons become more energetic and eventually "spill" into the upper valley, where they lose energy and where the mobility is similar to that of silicon. Thus the high field-saturated velocities are alike for bulk GaAs and silicon. In the transition region between the low-field and high-field regions, near the critical field, the slope of mobility reverses. This reversal corresponds to a region of negative resistance unique to materials with the GaAs band structure (typically other III–V compounds). The cause is the lessened energy as electrons spill from the main to the satellite conduction band valleys. The feasibility of certain microwave oscillator devices is due to the negative resistance property.

Another interesting feature of the GaAs band diagram is the way the extreme ends of the valence and conduction bands line up (are at the same momentum). This alignment defines a direct band-gap material and leads to an efficient cross section for optical transitions.

To elucidate, electrons that have been excited into jumping from the valence band into the conduction band, can collapse back to the valence band, and give up their potential energy by emitting 1.4-eV photons. Electrons that have been similarly excited in indirect band-gap materials (such as silicon), collapse back to the valence band by "emitting phonons," meaning that they dispose of their energy by heating the crystal by means of lattice vibrations.



Properties of gallium arsenide and silicon

Property	GaAs	Silicon
MOS grade thermal oxide	No	Yes
Thermal conductivity, W/cm-K at 300 K	0.46	1.45
Linear thermal expansion coefficient, $(°C)^{-1}$	5.9×10^{-6}	2.6×10^{-6}
Breakdown field, V/cm	4	3
Relative dielectric constant	12	11.8
High-quality n-type diffusion	No	Yes
Electron mobility in n-type material, surface / bulk, $cm^2/V\text{-}s$ [a]	N.A. / 4000	400 / 900
Bandgap	Direct	Indirect
Total dose radiation tolerance, rads	$<10^8$	10^6–10^7

[a] Where ND = 1017/cm^3 and T = 300 K
N.A. = not applicable

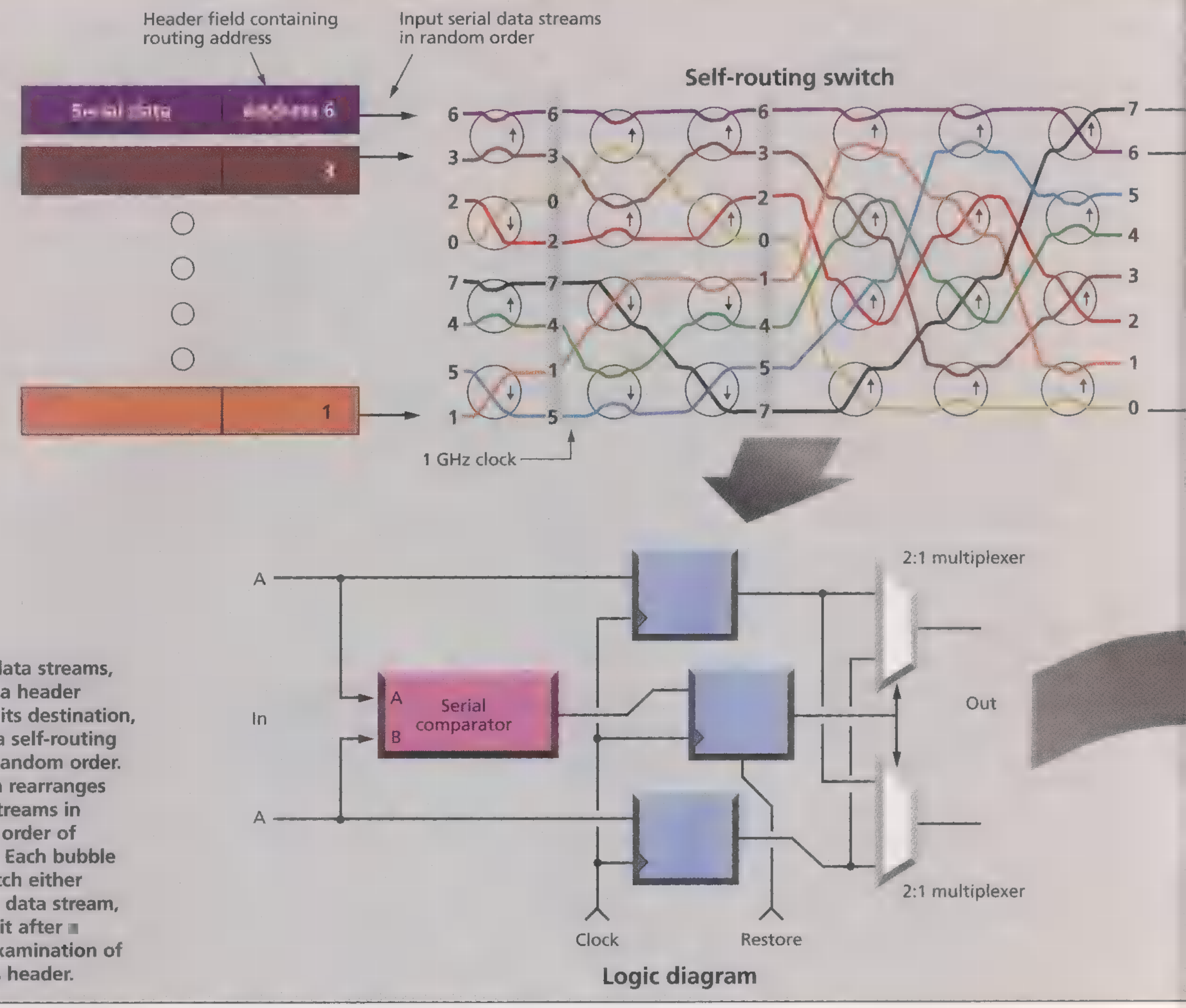
mance. In sharp contrast, reducing the power supply voltage in silicon CMOS ICs proportionally increases delay. The difference is consequential, for as feature sizes are reduced in any VLSI technology, the external voltages must be reduced; otherwise the electric fields internal to the transistors will not remain below breakdown.

As to exactly how large the transistors are and how far apart the wires are, those details fall within the purview of technologists. From a VLSI designer's perspective, any variations in these factors show up quantitatively in terms of delays and power dissipation (as embodied in simulation models) and in terms of chip component budgets.

To gain a feel for what is involved in working in 0.5-µm VLSI technology using GaAs direct-coupled FET logic rather than silicon CMOS, chip design teams might contemplate the items on the following list:

- A typical gate delay of 70 ps, as against 150 ps for a similar load.
- Typical gate power of 30–100 µW, independent of frequency, as contrasted with 2–3 µW/MHz (or 200–300 µW for a 100-MHz device).
- Total static RAM embedded in VLSI of 16KB, as against 64KB.
- Delay of this static RAM of 3 ns, as against 7.5 ns for a 1Kb-by-9 block.

The numbers in the list indicate the technical tradeoffs: GaAs VLSI has faster logic gates and faster static RAM, while silicon VLSI needs less power and less space per transistor. Silicon SRAM cells are smaller mainly because they use only four transistors, compared with six for GaAs. Incidently, high gate leakage cur-



Serial data streams, each with a header indicating its destination, flow into a self-routing switch in random order. The switch rearranges the data streams in ascending order of addresses. Each bubble in the switch either passes the data stream, or crosses it after a bit-wise examination of its address header.

rents in GaAs transistors make DRAMs impractical—no great loss since DRAMs are rarely embedded in logic VLSI.

A few other distinctions between GaAs and CMOS should be noted. In GaAs technology, the lack of insulated transistor gates means that all logic elements (logic gates) use up power regardless of the switching state. In CMOS technology, gates use no power when idle; of course, while switching, they do use power, and the faster they switch, the more they consume.

Now a digital VLSI chip is an assemblage of hundreds of thousands of logic gates. In many applications, particularly in computers, a fair number of these gates is idle at any given time. This inactivity reduces the power drawn on average by each chip for CMOS, but not GaAs VLSI, whose higher performance therefore often comes at the cost of higher power.

Not complementary

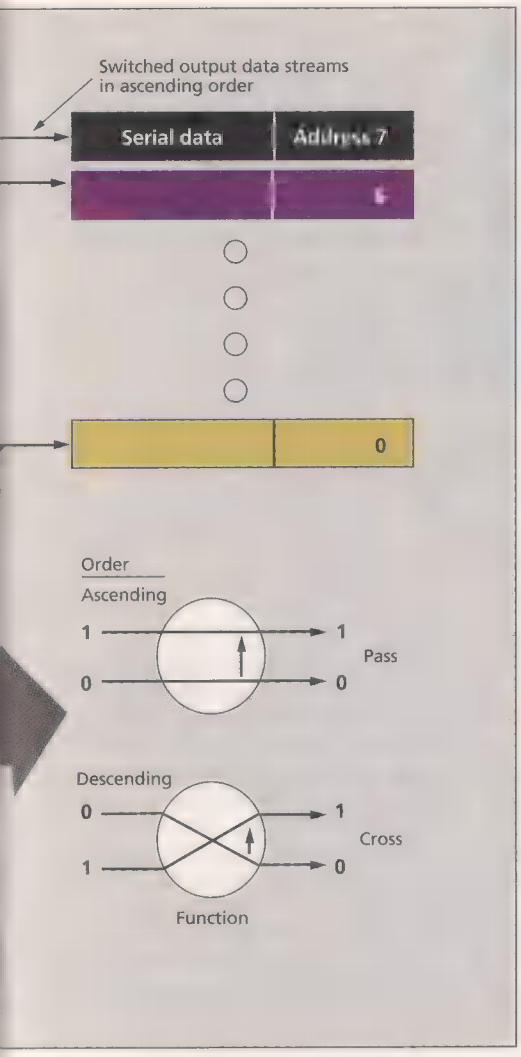
One natural question remains unanswered: why not emulate the silicon CMOS structure, that is, use complementary n-channel and p-channel devices? There are two good reasons for not doing so.

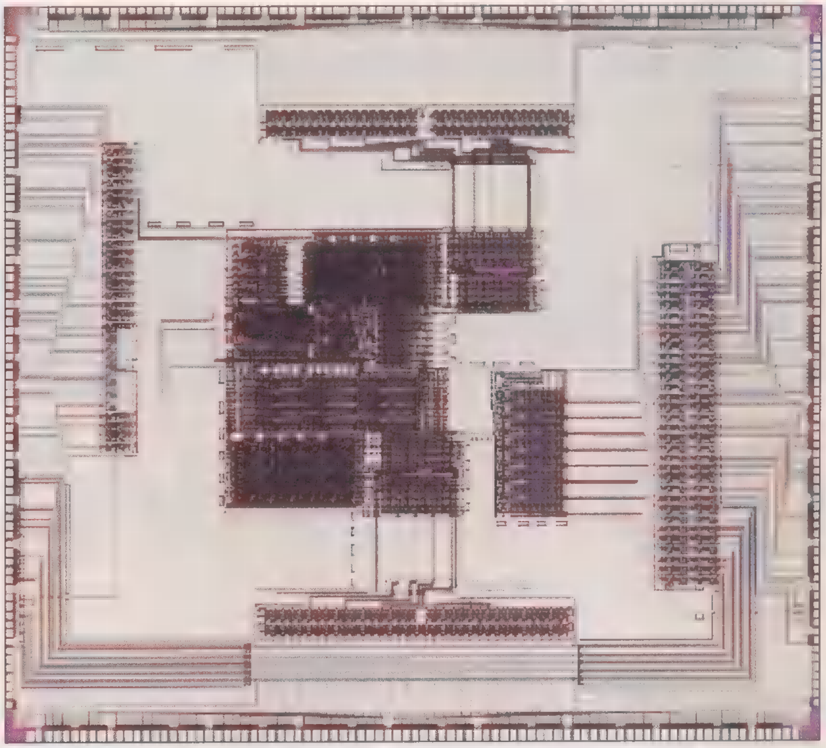
In the first place, electric charge carriers move faster in n-type material (where they are electrons) than in p-type material (where they are holes), and this difference is more marked in GaAs than in silicon. In round figures, the charge carriers move at about three times the speed in n-type silicon as they do in p-type silicon, but at about 10 times the speed in n- versus p-type GaAs. As noted earlier, the current output capability of p- and n-channel devices must be balanced, and this matching requires an inverse ratio in the transistor sizes. The matching is do-able for the 3:1 CMOS ratio, but too cumbersome to be practical for the 10:1 GaAs ratio.

Secondly, the gate and channel of a transistor on a GaAs IC are linked by a dc path that draws current in forward bias. The path is in effect a diode, and a very leaky one at that in a p-channel GaAs device. In other words, many of the benefits of CMOS, such as zero standby power dissipation, are unobtainable from GaAs—as yet. (The second objection may be removed in the future by using the more complicated heterojunction structure, in which a higher diode barrier would leak less current.)

To an overwhelming degree, VLSI technology development has been and will probably remain focused on silicon CMOS. Inevitably, then, GaAs VLSI trails behind CMOS both in feature sizes and in number of transistors per chip. This minor league status limits its application in some cases—wherever the greater speed of GaAs transistors is less necessary than the greater number of transistors possible with silicon CMOS.

As VLSI technology evolves toward smaller features, power supply voltages need to be reduced to keep the electric fields manageable within the smaller transistors. This requirement works against CMOS but for GaAs. In CMOS chips, a shrinking supply voltage slows the signal unless offset by shrinking transistor geometries in successive generations of the technology. In the case of GaAs VLSI, the power supply may be shrunk down to





▲ **A 1-GHz, 8-by-8, self-routing switch is fabricated in 0.6-μm GaAs. It is eight times as fast as a comparable CMOS device, yet uses only half the power.**

about 1 V without any direct effect on signal delay. This fact will loom larger as VLSI feature sizes descend into the deep submicrometer range, below 0.5 μm.

Compute and commune

GaAs VLSI appeals little to microprocessor makers, even though a doubling of performance could be guaranteed with features the same size as on a silicon CMOS IC. The investment required is both sizable and hard to justify, since few microprocessor architectures are profitable on their own anyway.

The technology is being used for some central processing unit (CPU) design, all the same. It is very much at home in minisupercomputers, an application that sets aggressive targets for system performance. To perform well enough, the CPU is split into several VLSI chips, and the whole system operates at the CPU clock rate. (By contrast, the internal clock of microprocessors is a multiple of the system clock.) Vitesse Semiconductor Corp. produces GaAs ICs that form part of a supercomputer's central processing unit. These chips use four levels of metal and contain more than 1.2 million transistors.

Naturally, GaAs VLSI is also in wide use in chips that support the CPU. Examples are bus interface circuits and cache-controllers. Triquint Semiconductor Inc., Beaverton, Ore., also makes GaAs ICs for computers; examples are a timing circuit with 25 000 transistors and a phase-locked loop on a 31-mm² chip.

The economics of minisupercomputers strongly favor GaAs VLSI. Its competition here is up-market silicon bipolar technology, rather than CMOS, and in development, product, and operating costs it undercuts its expensive rival. The cost of development is reasonable, because of a shorter design cycle due indirectly to the speed margin of GaAs, which allows enough leeway for automated design techniques to be used. The product costs less, since a given level of performance dissipates less power in GaAs VLSI—and with none of the exotic cooling hardware needed for silicon bipolar ICs. Finally, the system's operating costs are lower because of this lower energy requirement.

In communications, a prime use for high-performance digital electronics is in the interface to the optical-fiber trunk lines of serial data links. At this interface, digitized phone conversations, e-mail, bank transactions, and more are multiplexed into a single serial high-frequency data stream, converted into optical pulses, and transmitted along optical-fiber cable—an application that is ideal for GaAs VLSI with its optical affinities.

The demand for this type of communication is exploding and pressuring service providers to move onward and upward to ever higher bandwidths. Equipment for data rates of up to 2.5 gigabits per second is currently in volume production; 10-Gb/s systems are in development; and 40-Gb/s systems are in the R&D stage at most of the large global providers of telecommunication systems and services, including AT&T, Northern Telecom, and NTT.

The high-performance VLSI requirements for serial data fall into two general categories: transmission and switching. In the first, many lower-frequency digital data streams are converted into a single high-frequency digital-bit stream, and vice versa. Since the serial data is grouped into packets, these chips must also add routing headers to these packets, detect frame boundaries, and enact other functions having to do with sending messages.

In switching, data packets flowing in from several sources are processed into outgoing packets that are sent on to their destinations, as each packet's routing information directs. The system is like a railroad yard, where the incoming trains with their box cars of cargo are separated and reassembled into new trains and dispatched to their respective destinations. Obviously, the general switching problem

VLSI transistor speed: GaAs versus the rest

Technology	Device type	Smallest feature size, µm	Unity–current-gain crossover frequency, GHz
Standard devices			
Silicon	N-channel MOS	0.6	8
Silicon	Bipolar	0.6	13
Gallium arsenide	FET	0.6	30
Exotic devices			
Silicon germanium	Heterojunction bipolar	0.25	100
Indium gallium arsenide	Heterojunction FET	0.25	340

is functionally complex. In addition, the high data rates of optical-fiber systems (2.5-Gb/s serial rate is in production today) test the mettle of VLSI technology.

Today's switching systems cope with the inrush of packets by paralleling the data. The packets' header fields, which detail their source, destination, and other routing information, are stripped off. All the packet manipulation is performed at less than the data rate. And new packets are tagged with new headers and shot forth at high serial data rate.

One approach that somewhat simplifies the process is the so-called self-routing switching technique [see figure, p. 38]. Here, the headers are interpreted on the fly at the full serial data rate, and the switch automatically configures itself accordingly. This technique lays heavy demands on semiconductor technology to perform on a par with optical-fiber serial data rates. But GaAs is up to the task, and the concept has been implemented as an 8-by-8 switch using 0.6-µm technology [see photograph, p. 39].

The chip is a good illustration of GaAs VLSI performance, especially as all its elements are always switching at a 1-GHz clock rate. In a comparable generation of silicon CMOS, the switch would operate at no better than 125 Mb/s (one-eighth the GaAs rate) and would consume 50 percent more power than usual, because none of the elements is ever idle. As for silicon bipolar technology, it could outstrip CMOS, but power dissipation would be prohibitive.

In fact, GaAs VLSI is a natural in many areas of communication ICs. Triquint Semiconductor makes a 1 GHz, 32-bit accumulator/ROM for direct digital synthesis, a 1.2 Gb/s multiplexer, and a forward error-correction engine, all chips with 20 000 to 40 000 transistors.

Expense account

Tradeoffs and comparisons with silicon are generally reviewed by system manufacturers whenever they have to pick a technology for a new system design. If a custom chip is required, the tradeoffs are made consciously; for standard products, they are implicit in price and delivery.

Technical tradeoffs have already been discussed, but what of manufacturing costs? They loom ever larger as chip volumes increase. Granted, VLSI manufacturing facilities of similar capacity cost about the same for GaAs as for silicon. But not all of the factors that influence the incremental manufacturing cost of VLSI chips are the same for the two processes.

For instance, the starting material is more expensive in GaAs. But (as noted earlier) this drawback is partially offset by the simpler GaAs VLSI process. In the end, the cost of the blank wafer is only a small fraction of the cost of the completed wafer.

Again, GaAs VLSI technology is moving from 10- up to 15-cm wafers, trailing silicon's simultaneous move from 15- to 20-cm wafers. Thus for chips that are alike in size and yield, silicon CMOS VLSI offers you more for your money. (This is not true for other silicon technologies, though.) The savings due to the cheaper, larger blank wafers of bipolar and biCMOS VLSI are no match for the lower cost of the GaAs VLSI process.

Fabrication costs are ultimately driven by manufacturing efficiency. With the proliferation of GaAs VLSI products and rise in manufacturing volumes, GaAs VLSI prices will follow a steeper downward curve than silicon technologies, including CMOS.

Some predictions

To sum up, each generation of VLSI technology can outperform its predecessor, thanks to reductions in chip geometry. But as features shrink well below 1 µm, electric fields must also be contained by reducing power supply voltages. This last turn of events slows signals in MOS ICs but not—at least until the 1-V level is reached—in GaAs ICs.

Moreover, GaAs transistors will surpass even their present record-breaking performance if built as heterojunction devices [see table above]. Completely new VLSI concepts will then be implemented, like chips with RF receiver and transmitter front-ends, realized with no greater process complexity. Imagine an all-digital radio in which the RF signal is converted directly into digital signals and all of the subsequent signal processing is digital. The upshot could be truly inexpensive transmitter/receivers, since most circuit adjustment would be eliminated. Heterojunction GaAs devices could have optical transmitters and receivers incorporated alongside them in VLSI circuitry, opening up other areas of application.

The question of the hour, though, is this: what markets is GaAs VLSI poised to dominate now? In other words, where is GaAs VLSI clearly the cost-effective solution? At present, the fastest-growing segment is in the manipulation of high-speed serial digital data.

In the computer area there are several burgeoning applications, such as 1-Gb/s transfers of the torrents of data that rush between disk arrays and CPUs. In telecommunications, the fastest growth is in the interface with optical fibers, where serial data is processed at 2.5 Gb/s today and maybe 10 Gb/s tomorrow. In short, today's demand for GaAs VLSI is being driven by the market for high data rates that conform to internationally sanctioned standards. (Examples are fiber-channel for disk interface and Sonet or SDH for telecommunication optical-fiber interface.)

Since high-speed connections must exist between CPU buses, between CPU and disk, and between CPU and local- and wide-area networks, the pooled market is on the brink of sudden expansion. It will be most thriftily served, and therefore may well be dominated, by GaAs VLSI. ◆

To probe further

The *Technical Digest of the IEEE Gallium Arsenide Integrated Circuit Symposium*, October 1994, contains the latest information on this topic.

"GaAs Digital VLSI Device and Circuit Technology" is discussed by James Mikkelson in the *IEDM Technical Digest*, December 1991, p. 9.1.

James Blakemore considers "Semiconductor and Other Major Properties of GaAs" in the *Journal of Applied Physics*, October 1992, pp. R123-R181.

A thorough and up-to-date text is *GaAs High-Speed Devices*, by C.Y. Chang and Francis Kai (John Wiley & Sons, New York, 1994).

About the author

Ira Deyhimy is vice president of product development at Vitesse Semiconductor Corp., Camarillo, Calif. Before founding Vitesse, he was manager of integrated circuit engineering at Rockwell International. He has over 22 years of experience in GaAs electronics.

WHERE BUSES CANNOT GO

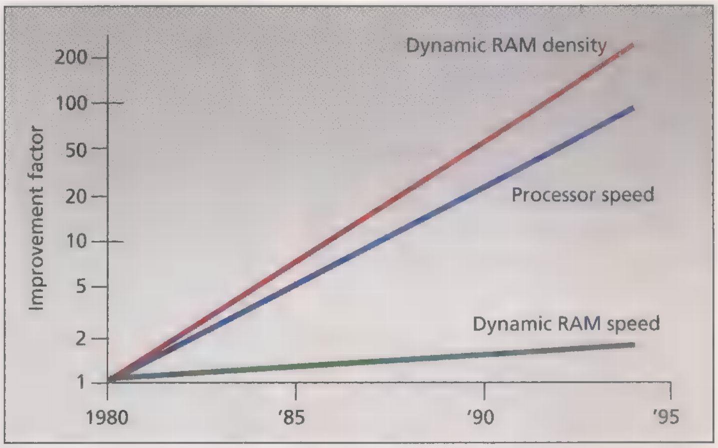
No aspect of computer design is sacred—not even the system bus, which is giving way to switches in multiprocessing systems, where performance is key

SYSTEM BUSES, WHICH STRING COMPUTERS together out of circuit boards, have come to strangle system performance in many cases. Another interconnection architecture, though, can free a system from the bus's clutch. Variously known as a switch, crossbar, or crosspoint, it has long been used in specialty computers and is now making its way into lower-cost machines.

Since the two architectures have co-existed for some time, why is the crosspoint approach only now coming to the fore? The answer lies in the state of the art back in 1980, when system buses were invented, and the advantages that crosspoint interconnects can bring today, when its special requirements are easier to meet than they were once.

Fifteen years ago, digital logic was not very dense, and numerous circuit boards were needed to hold enough of it to build a computer. Then the boards had to be interconnected. The distance between them hardly mattered, because the logic used was so much slower than the speed of electrons in metal traces. Nor did the then-current technologies for circuit board fabrication, chip packaging, and connectors allow a lot of signals to be routed among pieces of logic. Consequently, having a large number of boards share a single communication path—the bus—was economical and had no effect on the performance of most systems.

Today, the logic for a complete computer fits in a few square centimeters. Transistors switch so fast that signal delays between chips on boards and between boards degrade computer performance. Interconnections are still costly, but dense connectors, board fabrication advances, and new chip packaging have made a difference.



▲ **Ever since computer buses became popular, the speed of processors has risen more or less in step with the capacity of dynamic-RAM-based main memory, but memory speed has not kept up.**

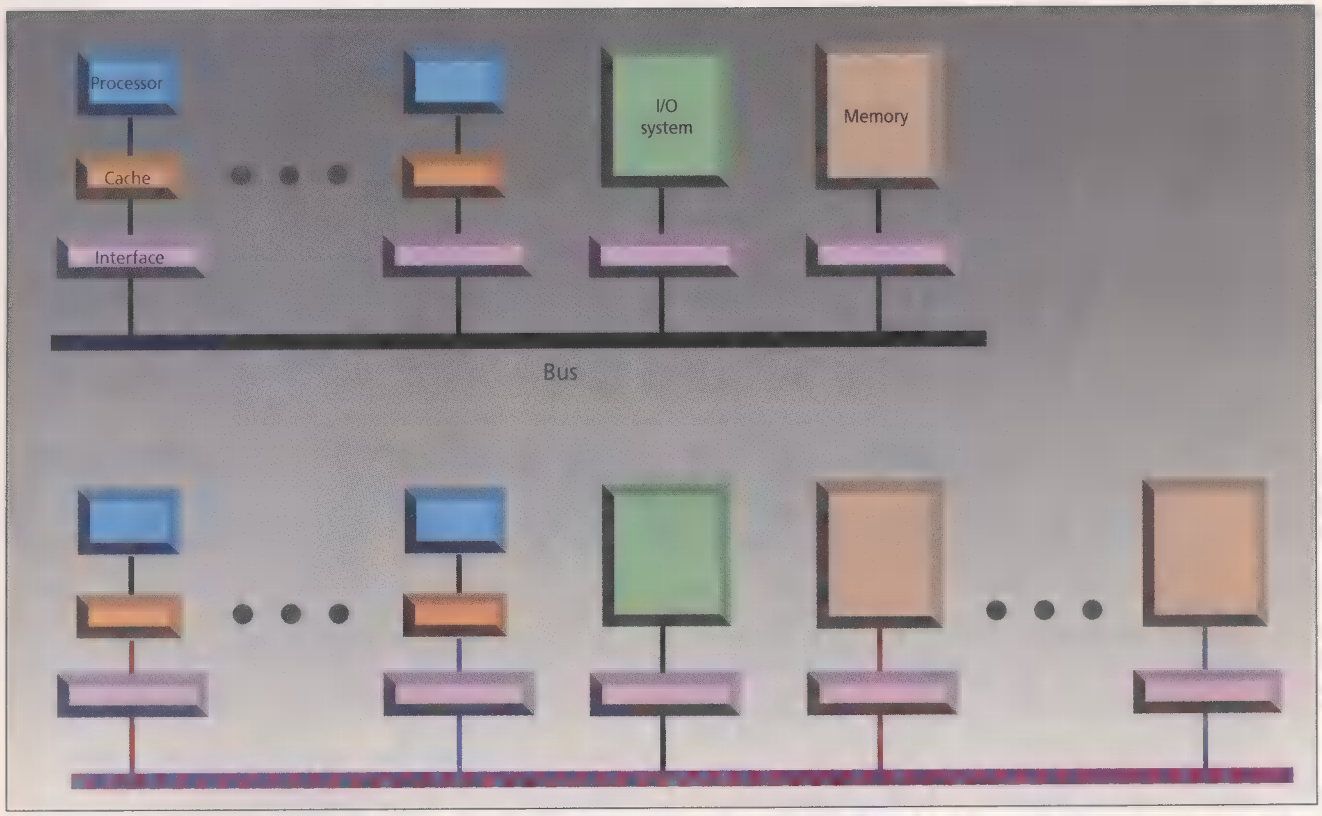
But the most dramatic changes have been in the transistor-based logic ICs themselves, specifically in processors and memories [see graph]. In 1980, an integer ADD instruction on a Motorola MC68000 took 600 ns; today it takes 1/90 of the time—6.7 ns—on a MIPS R4400. Back then the state-of-the-art dynamic RAM was 64Kb, whereas 16Mb chips are now in volume production. Relative to processors, however, DRAMs have improved only modestly in speed. The time to read a DRAM in 1980 was 120 ns and today it is 60 ns.

Hardly changed at all is the ability of connectors and wires to transfer signals. Improvements in their inductance parameters have produced only a slight increase in the speed at which they move signals. As a result, the familiar bus connecting a group of processors and I/O channels to a single global memory is throttling system performance, because the processors stall while waiting for the data they requested. How long this stall lasts depends not only on memory and bus speed, but on the amount of contention among processors for access to memory locations and for the use of the bus as well.

There are several ways in which the system architect can attack this bottleneck. He or she can:

- Reduce the frequency of pro-

AARON BOXER
Concurrent Computer Corp.



In the simplest multiprocessor architectures (top), the speed of a small static-RAM cache offsets the slowness of main memory—but only to a degree, because the processors must still battle with each other for bus time and shared memory, to the detriment of system performance. Splitting up memory and breaking access to it into sequential stages (bottom) makes more efficient use of the bus, but the resultant system is very complex.

cessor accesses to memory.
- Increase the memory bandwidth.
- Reduce the travel time of signals between a processor and memory.
- Increase the interconnect bandwidth among processors and memories.

Making all these improvements yields system architectures akin to those of massively parallel supercomputers. Meanwhile, silicon and packaging technology have been refined to the point that the crossbar architecture can vie with the system bus for a place in low-cost multiprocessors.

More specifically, the crossbar is well suited to use in distributed memory systems, where there is a need for broad pathways for communications between the chunks of memory themselves. The roots of such an approach go deep. In fact, it may be said to have started with an idea for keeping as much data traffic as possible out of general circulation: cache memory.

Defining terms

Application-specific integrated circuit (ASIC): a chip designed by its end-user using logic libraries supplied by the chip fabricator.

Bus: a group of signals and a signal protocol that allows boards to interconnect and communicate.

Cache line: the amount of data (almost always more than is needed immediately) that a processor fetches from memory each time it fills its cache.

Processor stall: a state in which the processor is executing no instructions because it is waiting for some external system event.

Crosspoint: a switching circuit that can dynamically create signal paths among multiple boards.

Fewer calls

Equipping a processor with small but fast caches of memory is a popular way of saving the bus from being swamped with traffic to and from the main memory [see diagram above]. However, it is not well suited to every application.

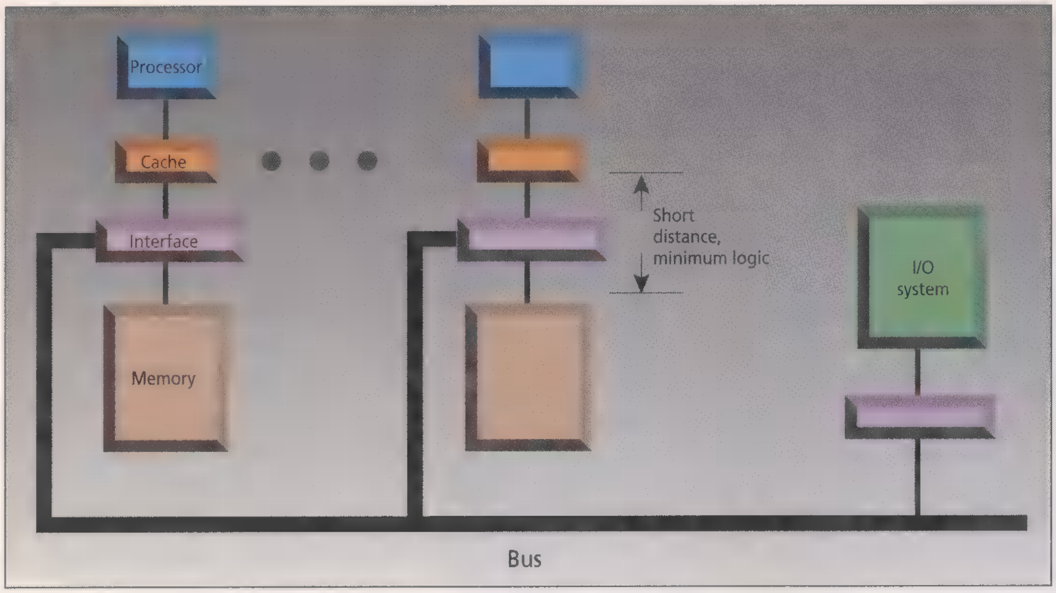
A cache is a little static RAM placed close to a processor. Digital logic tries to keep it full of copies of data from those main memory locations that the processor is most likely to need. The nearby cache can supply it much faster than DRAM memory on the bus, and the bus is left free for other uses.

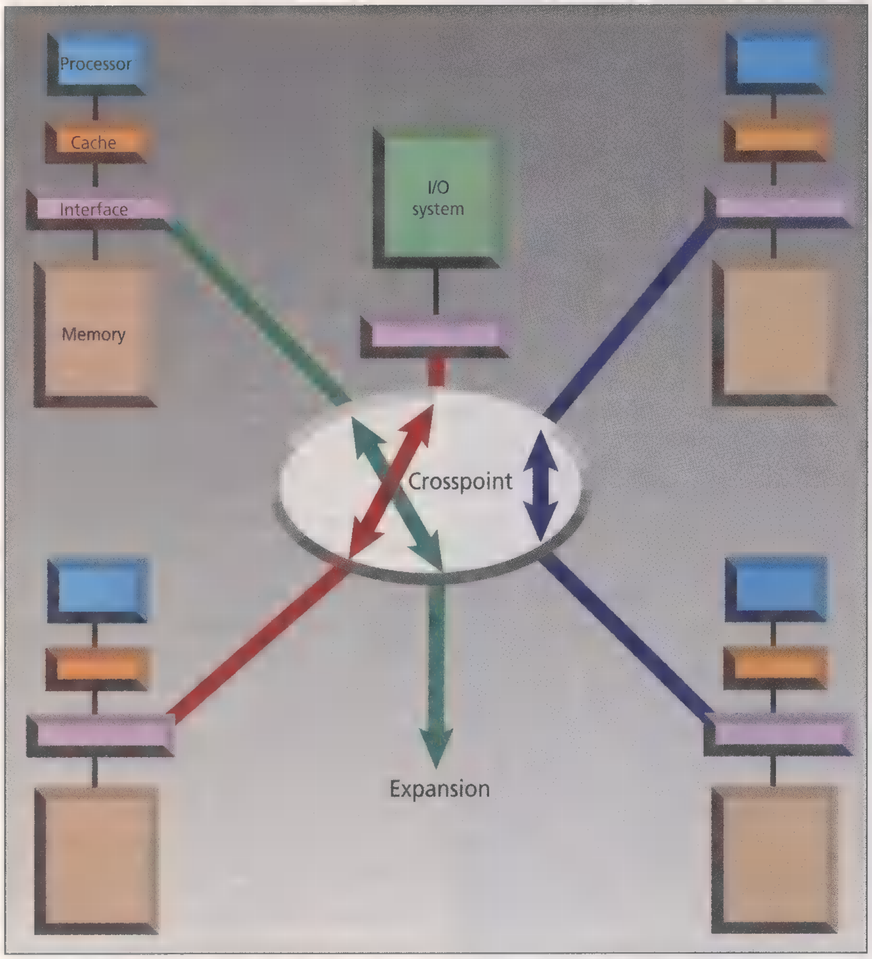
To decide what to copy, caches assume two things. First is the tendency for a processor to fetch data from consecutive memory addresses. This so-called spatial locality arises because sequences of computer instructions are executed from consecutive memory locations and because compilers allocate arrays and data structures in contiguous blocks of memory. In general, when copying needed data from memory, a cache also collects some extra data from nearby. The odds are good that the processor will need this so-called prefetched data soon.

The other program characteristic that caches use is temporal locality—the tendency for a program to reuse memory locations frequently. It happens when instruction loops are executed many times, to update variables and access constants.

The large mismatch between processor and DRAM speeds and the bus bottleneck described earlier mean that even small losses in cache effectiveness can damage performance. For example, four processors, each running at only 1.5 percent cache miss rate, would use the bus and DRAM memory for less than one out of 50 memory accesses. Yet even this low rate of usage can engulf all the bandwidth of a 64-bit-wide bus and its DRAM memory.

Sometimes a 1.5 percent miss rate is easily reached. For instance, real-time applications do a lot of context switching, where the processor is interrupted and asked to switch to a new task. But the new task's data are highly unlikely to be in current cache. Signal analysis applications, too, require a lot of data I/O and will have





When memory is distributed among the processors so that each has its own allocation, they need not fight over the bus for memory access, but must still rangle to communicate with each other and with the I/O system.

A multipoint switch that is able to simultaneously interconnect several pairs of subsystems maximizes the number of communications that can take place simultaneously. The use of very large-scale integration and current chip-packaging techniques make such switches practical.

poor cache behavior, because new data floods in steadily.

In such "cache buster" applications the processor will be constantly calling on main memory. So to increase performance, the architect must provide more memory and more interconnect bandwidth.

There are several techniques for attacking the memory bandwidth limitation inherent in the 60-ns access time of today's DRAMs. The two that are popular in high-performance system design are memory interleaving and multiple memory systems.

In memory interleaving, the memory and its controller are designed so that adjacent addresses are held in different DRAMs. The technique works well because caches prefetch several contiguous addresses when the processor accesses a single address.

When the memory controller sees one address, it accesses all the DRAMs at once and assembles the data into the contiguous block that the cache requires. The DRAM access time is still 60 ns, but DRAM bandwidth is improved because more bits are fetched per unit of time. The memory controller is a little more complex and the traffic between DRAM and the controller is a lot greater. The use of this technique is rare in PCs, but universal in workstations and high-end computers.

For multiprocessors, another technique is to have several memory systems on the bus so that several accesses may occur at one and the same time. This succeeds only if there are several processors accessing addresses in different memories.

The bus also has to be more complex. Simple buses must be held idle from the time a processor requests a read operation until the memory returns the data; thus only one memory access can occur at a time. Multiprocessors often employ more complex, split-transaction buses that allow the bus to be used while a memory controller is fetching data from DRAM. In the meantime, another processor can make a read request to another memory.

Several factors contribute to read latency, or how long a processor must wait for a response to its read request. The amount of interface logic between processor and memory matters. Nanoseconds go by while the processor's read request is passed through an interface to the bus, and then from the bus through another interface to

start the DRAM access [see diagram, p. 42]. Transfer of data back to the processor is again held up by both interfaces.

Another contributor to read latency is physical distance. Buses need to be long enough to connect a number of boards, and each board adds a capacitive load to the bus. Both the length of the wire and the number of capacitive loads slow down signal propagation. It can take more than 5 ns for a pulse to traverse a 300-mm bus with a dozen boards attached to it. This transit time represents a large fraction of the 20-ns-or-less clock period that is general in board design today.

Finally, there is contention among the processors for use of the bus. Even on the split-transaction bus mentioned earlier, one processor can be stalled while memory returns data to another processor over the bus.

Thus a third bandwidth-increasing technique—found mainly in specialty systems and massively parallel supercomputers—is to distribute memory so that a portion of it is close to each processor [see upper diagram, p. 43]. Then a processor waits around less because there is only one interface between it and memory. Putting the memory on the same board only centimeters away from the processor reduces transit delays and also its need to contend for the system bus. Only when an I/O system or some other processor on the bus has to talk to that memory will there be contention that stalls the processor.

An application that shares rather little data among processors can get all the benefits of physical proximity and reduced contention that are provided by distributed memory. Many applications, especially real-time ones, fit this model of loosely coupled cooperating tasks.

The distributed-memory architecture is also well positioned vis-à-vis advances in DRAM architecture. A distributed-memory system shrinks those portions of read latency due to contention for the bus, interface delays, and signal propagation time. A big improvement in DRAM bandwidth will have a large effect on read latency. And Rambus, for example, is a new DRAM chip interface that promises very high bandwidth into the chip.

There are two ways to extend interconnect bandwidth: widen the buses and add more paths. Widening the bus by adding more wires allows more bits to be transferred between boards at a time. This option is often to be found in recent multiprocessor systems based on reduced–instruction-set computing (RISC). For example, the Power Challenge Series from Silicon Graphics Inc., Mountain View, Calif., has a 256-bit-wide data bus, while the typical 486-based PC has only a 32-bit data bus.

The alternative is to create a number of simultaneous paths with switching logic [see lower diagram, p. 43]. Switching dynamically routes each transaction from the sending board to the receiving one over a separate set of wires. Recently, this has been done in low-cost machines such as the Raceway systems from Mercury Computer Systems Inc., Chelmsford, Mass., and in the mid-range Maxion line from Concurrent Computer Corp., Westford, Mass.

Like the wider bus, this approach also results in more bits being transferred at

A crosspoint implementation

Concurrent's Maxion line of real-time multiprocessor workstations are based on MIPS R4400 reduced–instruction-set processors with distributed memory and crosspoint switches. Systems range in price from about US $40 000 for an entry level dual-processor system to over $200 000 for a full-memory, four-processor unit.

To meet the requirements of both military and commercial applications, all systems are built in a VME 6U format—a choice that drove more design decisions than any other consideration. A VME 6U board is about 350 cm^2 in area and may draw a maximum of 9 A of 5-V power. Clearly not all the multiple processors, caches, memories, interface logic, and main communication-path switches required by such a system can fit or be powered on a single 6U board. So partitioning the design onto multiple, interconnected boards was a big issue.

For highest performance, crosspoint lines were not multiplexed, so the switch would also have at least 72 signals per connection because the data path of the MIPS R4400 processor is 72 bits wide (64 bits of data and 8 bits of error correction code). To control each crosspoint port, 15 more signals are needed, for a total of 87 per port. Further, about 25 power and ground pins are required to support them. Because the board area under the chip was needed to route all the signals to the crosspoint, a surface-mounting ASIC package is required. (A pin-grid array package would have had pins piercing through the board and blocking many signal paths.)

Heat had to be dissipated. Each port of the crosspoint uses about 50 000 CMOS gates and operates at a clock frequency of 50 MHz. This activity had to be cooled by forced air in the 1.5 cm between VME 6U boards.

A plastic package would have overheated, but a 304-pin metal quad flatpack developed by Olin Interconnect Technologies, Manteca, Calif., provided a low enough thermal coefficient to cool the gates. The square metal package had surface-mount "pins" spaced half a millimeter apart on all four edges.

Still, 304 pins were too few for the number of ports needed to support four processors. To get enough I/O pins, the crosspoint would have to be spread over several ASICs. But trying to put a full 72-bit port into one ASIC increased the I/O pin requirement, because each port needed pins to connect to their peers in other ASICs. Instead, the design of each 72-bit port was divided into smaller parallel slices of fewer bits.

In the end, each ASIC contained this small slice of all the ports and the interconnecting wire among them. The full 72-bit data path is made of several ASICs in parallel. The crosspoint data path slices operate independently, with no communication signals among them.

To keep the slices synchronized, each must receive some of the same control signals. Maintaining the timing and quality of these signals would be the toughest requirements of all because, like buses, the lines they must travel over went the farthest and had the heaviest capacitive loading. Detailed Spice simulations that included accurate models of the interboard connectors and the CMOS drivers determined a maximum length and loading. Using standard driver technology confined the implementation to six interconnected boards and six crosspoint slices.

From all this data, it was easy to determine that a six-port crosspoint implementation on six boards was the most cost-effective product. The crosspoint was implemented in six 240-pin metal quad flatpacks that, along with one VME I/O system, fit on one VME 6U board. A MIPS R4400 processor, 1MB cache, and 128MB memory were installed on another board. A third board with another VME I/O system was built for an expansion port.

If performance were not an issue, a bus-based solution would have been cheaper, because the crosspoint ASICs could be replaced by a passive backplane. But even with the more expensive crosspoint, the cost goals of the product could be met because the switch could be realized using standard ASICs in moderately priced packaging.

—A.B.

one time among boards, because it handles more simultaneous transactions. The crosspoint approach has some electrical advantages. While a bus significantly delays signal propagation because of wire length, a crosspoint's interconnect wire is only long enough to connect a processor board to the crosspoint board. The delay-inducing capacitive loading is reduced, because the two boards are the only capacitive loads on the line. So a crosspoint interconnect not only increases the number of bits per unit of time can be transferred on the wire, but it also reduces the time taken to transfer each bit.

Admittedly, a crosspoint design employs more signal paths, logic, and interconnect components than a bus. A bus has one signal path to which all boards are connected; a crosspoint has a signal path from every board to every other board to which it makes a separate connection. The latter scheme not only results in more signal paths but also requires more switching logic and interconnect components than the former.

Historically, all these elements were expensive in terms of dollars and circuit board area, so the bus remained the practical choice for general-purpose computers. But progress in silicon and packaging has changed the relative cost of interconnections and now make it possible to put crosspoints into lower cost general-purpose systems [see "A crosspoint implementation," opposite].

The crosspoint has some disadvantages, also. The number of connections to the crosspoint increases linearly with each board while they remain constant for the bus. The number of paths inside the crosspoint is a squared function of the number of boards, whereas it remains one for the bus. Therefore the crosspoint can connect only a few boards for the same cost as a bus. For a large number of boards, the bus is still more cost effective.

Preventing chaos

When the most effective techniques of expanding memory and interconnect bandwidth are applied, the result is a crosspoint architecture with distributed memory. But programmers still want general-purpose computers to have a unified—or global—memory model, in which each memory location has a unique address.

Further, data consistency must be maintained among all the caches in the system. The cache coherence problem arises when a processor writes new data into a memory location. All the other caches that may have copies of the old data must be informed that their data is no longer valid. In high-performance cache systems, the new data is not even written back to memory immediately. Other caches that need the new data may have to get it from the one cache with a valid copy instead of getting it from memory.

The traditional bus-based system "snoops" to arrive at this consistency. To be clearer, all the caches monitor the activity on the bus. When a processor changes the data in its cache, that cache puts an invalidate message on the bus, giving the main memory address of the changed data. The other caches see this message and discard any copy of the old data they may have.

When another processor tries to read from its cache's now-empty address, its request appears on the bus. The one other cache with the new data sees the request, stops the main memory from supplying old data, and itself satisfies the read request.

Snooping requires that all caches see all bus traffic. But part of the strength of the distributed-memory crosspoint architecture is that multiple accesses may occur simultaneously and in isolation from each other. (The read requests and invalidate messages are not broadcast to all the caches in the lower diagram, p. 43.)

No snooping

The problem of cache coherence is solved by a directory-based scheme—essentially extra memory for keeping track of which caches have a copy of a memory location's contents and whether new data has been written into it. This directory memory could be added at a number of places in the architecture, but the simplest and cheapest approach is to include it as extra bits in the distributed memory. This way, it has no need of a separate communication path to access it, and it can be implemented in DRAM, which is the densest form of silicon data storage.

A directory for a system with six caches requires 7 extra bits for each cache data line. Therefore a system with 64-byte cache lines would have only a 1.4 percent increase in memory size for the directories.

When a memory acts on a request to provide data from any address, it looks at the address's directory entry. If the entry shows the data to be valid, the memory sends it back to the requester and a directory bit is set indicating which cache got it. When any processor writes new data, its attached cache sends an invalidate message to the memory address of the old data. The directory entry for that address is examined, the invalidate is forwarded to any other caches using the data, and their entries in the directory are cleared. The bit for the sender of the invalidate message, however, remains set and the directory bit indicating that memory is no longer valid is set. The directory now knows which cache has the revised data.

The directory approach works better for invalidates than bus snooping does. In bus snooping, every cache must check every invalidate message that appears on the bus. Meanwhile, a processor trying to access its cache has to wait. A cache that can check invalidate messages without stalling its processor can be designed; however, it is more complex, costs more, and uses more board area.

But the majority of invalidates are not to shared data, and usually there is nothing to invalidate when the directory checks itself. The directory scheme optimizes performance for invalidates by sending them only to caches that have previously requested copies of the invalidated address contents. Optimizing a low-cost system design for high performance on invalidate messages makes sense, because they are the most frequent form of cache coherence activity.

When memory receives a read request for data that is valid only in a processor's cache, it duly forwards the request. The cache returns the valid data to memory, which responds to the original read request. A higher-performance (but more complex) approach is for the cache with the valid data to send it directly to the cache that issued the read request.

All the evidence suggests that computers will continue to get faster, denser, and cheaper. The shifting balance among the technologies involved is what causes changes in computer architectures. The same holds true for interconnection design. Distributed memory crosspoint architecture is not new, but silicon and packaging advances now make it practical for lower-cost multiprocessors. ✦

To probe further

For a good all-round book on computer architecture issues, see *Computer Architecture: A Quantitative Approach*, by John L. Hennessy and David A. Patterson (Morgan Kaufmann Publishers, San Mateo, Calif., 1990).

For a discussion of a similar architecture, look in the March 1992 issue of *IEEE Computer* for "The Stanford Dash Multiprocessor," by Daniel Lenoski and others (pp. 63–79). The June 1992 issue contained "A Survey of Cache Coherence Schemes for Multiprocessors," by Per Stenstrom (pp. 12–24) and "Directory-Based Cache Coherence in Large-Scale Multiprocessors," by David Chaiken and others (pp. 49–58).

About the author

Aaron Boxer is a senior consulting engineer at Concurrent Computer Corp., Westford, Mass., where he created the hardware architecture of the company's latest computer. He has been working on multiprocessor designs since 1981, when he helped start the computer company Masscomp.

COMPACT SIMULATORS FOR FOSSIL-FUELED POWER PLANTS

PC- and workstation-based systems cut plant operating and capital costs, also form a training ground for operators

ROY FRAY
Electric Power Research Institute

IN FOSSIL POWER PLANTS AROUND THE world, a new breed of plant simulators is winning a following. These "compact simulators" are based on personal computer and workstation hardware and can model a plant's operations accurately and in real time. They are both adaptable and mobile. With their aid, electric utilities are training more qualified power plant operators and designing tighter power plant control systems. The simulators are even being used to test untried power plant technologies.

Earlier simulators of fossil power plants were inflexible and expensive, and few were used. Typically, they cost in the millions of U.S. dollars, whereas the average compact simulator sells for `about US $500 000. An electric utility in Italy, Azienda Energetica Municipale (AEM), estimates that specifying conventional simulator technology at its Cassano Plant near Milan would have cost it over $1 million more than did the compact simulator technology it in fact used.

Broad benefits

Utilities project savings in the millions of dollars over the life of the simulator. The benefits flow from many sources, from reduced running costs (for fuel, operation, and maintenance) to lower capital costs (for control system retrofits and for longer-lasting power plant components).

A well-documented area of savings stems from operator training, which can be done more thoroughly with a compact simulator than without. At present, far more is spent on reducing equipment failures than on training operators, even though preventable human error contributes almost as heavily to losses in power production. The need for training is felt the more sorely as utilities tend to operate plants in "cycling" rather than in "baseline" mode—that is, with power output varied to match cyclic variations in load, rather than with the essentially constant output for which the plants were designed. Properly trained individuals can effectively operate the new environmental control systems (boiler and stack systems), apply programs for optimizing the life of a plant, and run the nontraditional types of power plants, such as coal gasification, fluidized-bed combustion, and combined-cycle units.

After learning the ropes on a compact simulator, plant operators know enough to foresee and prevent several disruptions ("trips") per year of the generating system's operation. Then there is an improvement of 0.25 to 0.5 percent in plant efficiency. Shutdowns are shorter: generating units recover from them more quickly, typically one hour faster. Operators themselves are refining methods of extending the life of plant components, for instance, by avoiding thermal cycles, those temperature variations that age components. Techniques for operating closer to environmental limits are also being practiced.

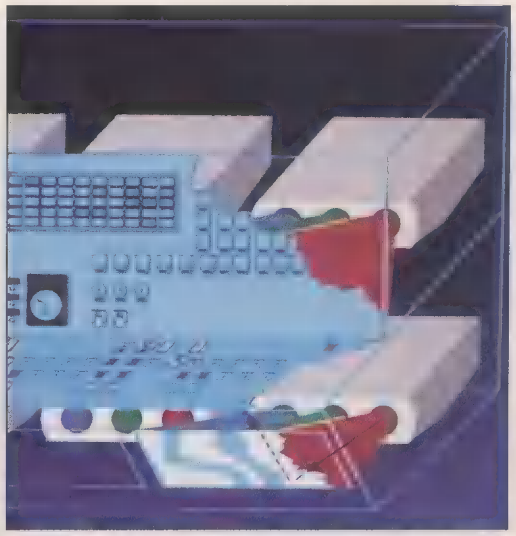
Depending on the application, utilities have documented annual savings of $1000/MW to $4000/MW by setting up operator training courses based on compact simulators. For a 500-MW unit, for instance, savings can hit $500 000 per year. In the case of Alabama Power Co., the tactic is expected to save it upwards of $23 million over 15 years—a highly desirable state of affairs when competition in the electric utility industry is becoming so much stiffer.

Control system applications

Many electric utilities are shifting their fossil power plant control from older analog and pneumatic systems to more effective computer-based digital systems. But when first started up, the new units need adjustment and operators trained in the new control philosophy and interface. Errors in

0018-9235/95/$4.00©1995 IEEE

PHOTOS: ELECTRIC POWER RESEARCH INSTITUTE AND MITRE CORP.



▲ Hard-panel emulation is one of several advanced technologies used in compact simulators for fossil-fueled power plants. It represents plant control panels in software by rear projection of full-scale, high-resolution images onto large touch-sensitive screens.

◀ This simulator system being installed at Boston Edison's Mystic Unit 6 emulates annunciator windows and computers (top), strip chart recorders and manual-auto stations (middle), and switches and indicators.

ELECTRIC POWER RESEARCH INSTITUTE

▲ Seated at the compact simulator for Southern California Edison's 750-MW fossil fuel power plant—Ormond Beach Unit 2—an engineer calls up a control function using a touch screen. The adjacent keyboad is identical to the one at the plant's control system. The three screens emulate hard panels at the plant as well as its Westinghouse Electric distributed control system.

control logic and mistakes by the operators can cause plant trips and equipment damage, as well as drag out the time it takes to commission the new system.

Duke Power Co., Charlotte, N.C., is replacing aging control systems in many of its fossil plants. The ability to design, debug, and tune the new units before plant start-up is all the more crucial because of the number of the replacements, strict schedules, and tight budgets involved. So to speed installation, a mobile compact simulator housed in a trailer is being used by the utility as an engineering testbed and as an operator training facility as well. Duke estimates that outages will be reduced by four weeks for the first generating unit and two weeks for each sister unit.

Simulation systems

AT THE HEART OF EACH compact simulator is a model that predicts the dynamic behavior of fossil plants and includes models of their control systems. A number of vendors offer a high-fidelity type specifically for fossil power plant engineering analyses and operator training. This equipment supplies rigorous transient thermal-hydraulic models of power plant components (such as turbine stages and boiler heat exchangers), along with run-time executives for program execution and software for building or modifying models of specific power plants. Equations used to describe the operation of plant components are based on first principles, using conservation of mass, energy, and momentum, and relevant relationships such as empirical heat transfer values.

Most of the simulation systems available include a library of models of power plant components. The models can be configured, parameterized, and executed. In the first step, configuration, the model of a component is retrieved from the library and linked to others. Next, parameterization is done by entering physical and operating data. Then the complete model is generated for the simulation system to execute.

In most simulator systems, a full set of instructor functions is to be found. These enable an instructor to maximize the value of the training. They include selecting different plant models, setting initial conditions, and interrupting model execution to emphasize a point. Other functions permit the instructor to backtrack at will to an earlier stage in the simulation, and to introduce malfunctions. There are even special functions with which he or she can evaluate students' proficiency. Instructor functions are typically embedded in the simulation executive and controlled from one PC or workstation in the system, the instructor's unit.

A compact simulator has three parts and may be configured in any of three ways. The parts are the model of the plant process (described above), the plant controls, and the man-machine interface between operator and plant. In all the configurations, the plant is simulated, but the plant controls and interface may be "emulated" (replicated using software) or "stimulated" (using duplicate sets of actual control hardware and software) or hybrid (using emulated controls but actual interface screens).

The three configurations

An "emulated" system thus emulates all three of the simulator elements—process, controls, and operator screens [opposite, top left]. One or more PCs or workstations execute the process and control system models, while other PCs drive the operator displays. The simulator executive and set of instructor functions usually reside on the same PC as the process or control model. The hardware is connected by a local-area network.

The comparative advantages of an emulated system include low equipment cost (since a PC is cheaper than duplicate control system hardware), flexibility, and portability, due to the use of readily available hardware and software. To apply the system to a different plant, it need only be loaded with the appropriate models and have its keyboard template replaced. The simulator may be run wherever there is a PC that meets the hardware requirements (ranging from a 33-MHz 386-based PC to a 100-MHz Pentium-based PC).

Drawbacks include the expense of reconstructing operator screens and the need to model the control system. Control system updates would entail modification of that model and/or of emulated screens. Thankfully, this task has already been eased for some brands of control systems by the development of translators—software that translates control logic and control graphics from control system platforms to PCs.

In a "stimulated" system, only the process is modeled, while controls and operator interface functions are supplied by a duplicate of the plant control system hardware and software [opposite, bottom left]. The simulator executive and instructor functions reside in one of the PCs that execute the process model. Full instructor functions are rarely available for stimulated configurations. Fast/slow time and replay are usually limited, because the simulation computer cannot take charge of the actual processors and memory. (But some control system vendors are already developing, or have developed, special interfaces that will address this deficiency.)

Another way to get round instructor function limitations is to resort to pre-set initial conditions. For example, the two-hour thermal soak period during unit start-up can be skipped by stopping the simulation after the soak has begun, and once it has ended, inputting conditions and restarting the simulation.

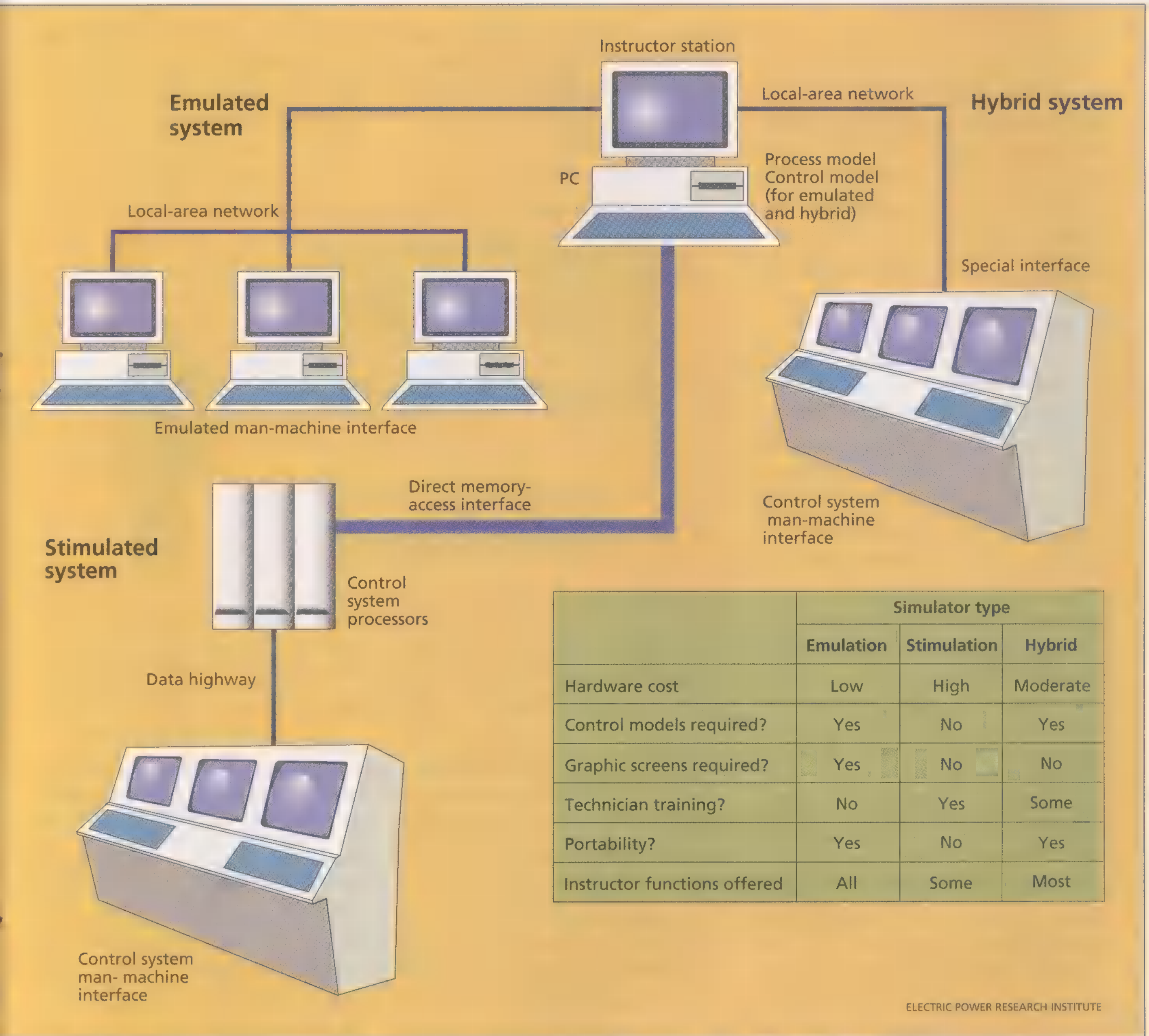
In stimulated systems, display screen and control logic software is simply downloaded from the actual control system. So the simulator can be easily updated to cope with control system changes. In fact, since the stimulated configuration uses a duplicate of the plant control system, it is often the approach of choice for control system engineering applications. Utilities have also justified their use of these systems in part by pointing out that the duplicate hardware can be used for emergency spare parts.

As for the downside of the stimulated configuration, it includes the high costs of buying duplicate equipment and the lack of flexibility and portability entailed by using this actual equipment. Obviously, since the simulation cannot be executed independently of the control system hardware and software, its use is confined to one installation, and it is constrained to represent only one type of control system (for example, Bailey, Bristol Babcock, Siemens, or Westinghouse).

In a hybrid system, the process is modeled and control logic is emulated, but the man-machine interface functions are provided by actual control system hardware and software (opposite, top right). One or more PCs and workstations execute the models of the process and control system, information on both of which is delivered to the operators' screens through a special interface. As for the simulation executive and instructor functions, they may either share hardware with the process and/or control system models or be distributed to separate processors.

The hybrid configuration can boast of moderate equipment cost, no need of emulated screens, and portability. The control system model makes it readily transportable to other locations for engineering analysis. But the need to build and update a control system model is a shortcoming.

To select the best configuration for their purposes, simulator designers weigh trade-offs between such factors as intended application, equipment cost, software tailoring cost, simulator flexibility and portability, and training needs. For example, if cost is the sticking point, an emulated configuration should be considered. If the main application is control system engineering, a stimulated configuration is probably the best option, because it uses an exact duplicate of the control system.



	Simulator type		
	Emulation	Stimulation	Hybrid
Hardware cost	Low	High	Moderate
Control models required?	Yes	No	Yes
Graphic screens required?	Yes	No	No
Technician training?	No	Yes	Some
Portability?	Yes	No	Yes
Instructor functions offered	All	Some	Most

▲ In an emulated system the key elements of a fossil power plant—plant process, plant controls, and operator interface—are modeled in software for PCs or workstations, and standard local-area network protocols serve data communication. In a stimulated configuration, the plant process is modeled in software, but the control system and operator interface use duplicate hardware. (In other words, the plant process software stimulates actual hardware.) Data highway refers to proprietary protocols supplied by the equipment vendors. In a hybrid system, the operator interface alone uses duplicate hardware. A special interface replaces the I/O interface in the actual application in the plant.

In the United States, the electric utility industry is becoming increasingly competitive, because of deregulation and the unbundling of the generation, transmission, and distribution functions into separate companies. Now more than ever, utilities must turn new technologies into quick payoffs.

Challenges remain

This state of affairs has at least two implications for compact simulators. First, to ensure wider use, they must be made even more cost-effective. Second, beyond their use for training and control system engineering, simulators can be profitably applied to the testing of new technologies. They can act as research testbeds to aid the design, testing, and debugging of new power plant technologies, such as advanced plant control schemes and automation systems.

Once a proven technology can offer an acceptable payback period, further development shifts the emphasis away from lowering costs and toward enhancing capabilities, improving ease of use, and expanding applicability. To stay up with the game, simulators must incorporate complementary technologies, such as expert systems, to increase their effectiveness and affordability.

Some utilities have special needs that new technologies must satisfy. Many are automating their fossil power plants in an effort to reduce labor and other costs. As part of this process, ever more complex plant control systems are being installed. An effective power plant simulator must

realistically emulate these controls and interfaces.

Current worldwide efforts to rise to the occasion are utilizing a variety of hardware and software technologies. For instance, computer platforms for simulators have evolved from cumbersome mainframes to supple networked groups of PCs or workstations. Advances in software development facilitate and speed up process model development. "Point-and-shoot" techniques enable power plant models to be constructed more quickly than was possible when line after line of computer code had to be written.

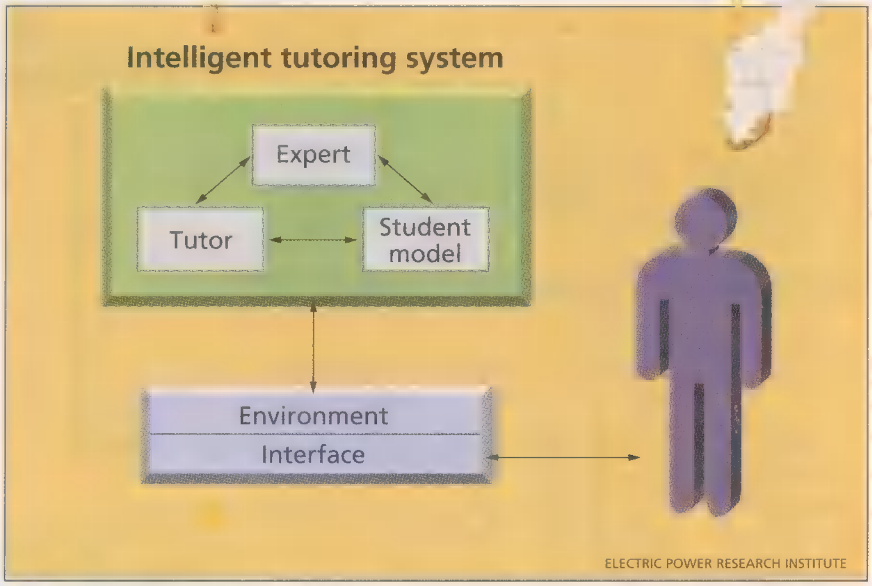
In another advance, mentioned earlier, the designer of a simulation system can now draw from libraries of existing models of power plant components and tailor them to specific plants. Modular modeling, as it is called, does away with painfully handcrafting a model of every power plant component—a process that when the model for an entire plant is involved, may require hundreds of thousands, if not millions, of lines of computer code.

Building on experience

This concept can be taken a step farther, and existing models of an entire plant be employed as the starting point for simulation system development. Of course, models of similar plants must be available, and that is more and more likely to be the case as more simulators are implemented. To wit, New York State Electric and Gas Co. looked through a simulation library maintained by the Electric Power Research Institute (EPRI) and identified a model of a generating unit very like one the utility wanted to model. The lucky find gave the utility a head start on a compact simulator for its Milliken plant.

While modular modeling aids the development of power plant models, the control system and operator displays have not been neglected. In one new approach, extra versions of control system and operator interface hardware, as well as special interfaces to link this hardware to the simulator control system, are being made available to utilities by vendors, at decreasing cost. Utilities are using this hardware and these interfaces for stimulated and hybrid configurations.

In an approach alluded to earlier, control logic and graphic screen "translators" have been developed for emulated and hybrid configurations. This software emulates control logic and operator interfaces for use in simulators. No longer is it necessary to manually code algorithms and to redraw screens. Computer programs have been developed that emulate the screens and control algorithms of several types of control system. Later, when a utility's control system is upgraded or modified, the simulator must also be modified to reflect these changes—a process much eased by these translators. More and more utilities are specifying translators when buying simulators.



▲ **An intelligent tutoring system has five basic components. While the expert module contains instructor knowledge and expertise, the student model includes the student's state of knowledge. The tutor module determines how to improve the student's knowledge. The tutoring environment employs a game-like strategy, and a Windows interface is used.**

Undoubtedly, compact simulators are most effective when combined with programs for training plant operators. But simulator-based training programs typically take several person-years to prepare and three or more months to present when they are developed in line with the nuclear utility industry practice.

Stepping into the breach, EPRI and Duke Power have joined forces on a set of guidelines for developing training programs. Persons using the document should be able to prepare an effective six-week simulator training program with about nine person-months of effort. The guidelines recommend, among other things, performing a simplified job and task analysis, identifying training objectives, matching objectives with simulator capability, and focusing on essential needs.

Intelligent tutoring

THE TRAINING OF OPERATORS by means of compact simulators promises to be further enhanced by expert system technology. The integration of the two is called intelligent tutoring technology.

In the past, instructors conducted simulator-based training at a central site. Today, simulators are low enough in cost to be installed at each power plant. The operators of these plants have unpredictable stretches of "dead time," when they could be receiving training on the simulators. But reductions in training staffs have set tight limits on the amount of time these simulators can be used for instruction in this way.

The intelligent tutoring system (ITS) is computer software designed to monitor operators and tutor them during simulator exercises. As an "intelligent" system, the ITS incorporates the knowledge of experts such that anyone with time on their hands during routine shift operations can use the simulator in a self-study mode [above]. This arrangement, incidentally, also extends the useful availability of the simulator.

South Carolina Electric and Gas Co., the first user and co-developer of EPRI's intelligent tutoring system, estimates that the system increases the benefits of compact simulator technology by as much as 25 percent. Moreover, Labein in Spain has developed an ITS, and personnel at the Santurce plant unit 2 in that country have tested the prototype ITS, called Santurcedem, with positive results.

In point of fact, the intelligent tutoring system is being used by utilities in modes other than strict self-study. For instance, it is being applied during a normal training session with the instructor present in person. Freed from the need to attend to every detail of the trainee's actions, the instructor can turn to more subtle aspects of the task in hand—for instance, whether or not the student is anticipating operating problems by examining trends in

plant parameters. This deepened perspective on the work improves the teaming between instructor and operator.

Enhancements to EPRI's intelligent tutoring system have added to its effectiveness and widened its range of applicability. Voice interaction, as well as additional graphic elements (photographs, animation, and video, for instance) have been added to supplement a text-based interface. The systems now produce a log of student activities after the training session for student review.

As additional ITS implementations are brought on-line, a library of ITS-supported scenarios will grow larger. EPRI is at present working on modules for beginning, intermediate, and advanced simulator training, including load change, drum level control, temperature control, trip recovery, and startup. Tools are even available that equip instructors to develop new ITS-supported training scenarios themselves.

The integration of expert systems and training may soon spread beyond the walls of fossil power plant control rooms. Other applications of expert system-aided operator training could include utility energy control centers—the nerve center of utility power system operation—as well as various process industries.

Hard-panel emulation

Advanced computer displays are a second technology that melds well with compact simulators. Many fossil power plants are being upgraded to soft control-system interfaces (such as displays and keyboards); but at a large number of plants, hard-panel interfaces like switches, meters, and actuator lights will operate unchanged into the next century. If compact simulator technology was to reach these plants, a way of simulating and displaying hard panels for simulator use had to be found.

The answer was to rear-project full-scale, high-resolution images of control panels onto large touch screens [see upper right photograph, p. 47]. By using these screens, the operator can actuate the hard controls. The technology enabled Boston Edison to afford a simulator for its fossil-fuel units.

Hard-panel emulation may even succeed in rising above simulators. As things stand at present in the control rooms of power plants, CRT displays open only a small window onto the plant's operation, and at scales smaller than life size. To use these monitors, operators switch between multiple levels of zoom to find the right controls and make them legible enough to read. It is often difficult to navigate the maze of displays. In addition, these monitors fail to effectively present operators with the "big picture"—an overview of plant operating parameters. Granted, some large-screen displays exist that provide a better overview of plant processes, but they are expensive and inflexible.

Certainly, large "soft" panels, like those based on hard-panel emulation technology, do suggest that methods of displaying instrumentation and actuation equipment will be limited only by the imagination. Since the images of controls in hard-panel emulation systems are computer generated, a programmer could alter how they look for greater clarity and ease of use, so that operators could react to their indications more surely and swiftly.

For example, one large display could show an overview of the entire plant process in schematic form. When an alarm flag popped up on a portion of the screen, the operator could touch the flag and view a subsystem process or component schematic, which would highlight off-normal parameter values.

The operator could even consult an expert on the diagnosis of a problem by conducting a video conference via a window on the screen. Operating procedures recommended as correctives by an expert system would be available at the touch of a button. These bright, clear displays would be at arm's length from the operator [see "Multimedia's push into power," *IEEE Spectrum*, July 1994, pp. 44–48].

Advanced computer display technologies may one day generate almost a "virtual plant" in the control room. A walk along a set of displays while zooming in on particular subsystem and component displays will seem almost like walking through the plant itself. The advantages of such an advanced system are many, including reduced costs due to improved operation, enhanced power plant design and engineering, and improved in-plant testing of new technologies.

Thus far, compact simulator technology has been applied to a wide variety of fossil plant types, using components and control systems from diverse manufacturers. Southern California Edison has worked with EPRI to develop these simulators at both subcritical and supercritical gas/oil-fired units, while Alabama Power's simulator is installed on a coal-fired unit. Another simulator models a 450-MW combined-cycle gas turbine plant, demonstrating the technology's applicability to power plants equipped with efficient new technology. The systems have even been applied to a compressed-air energy storage plant, and will soon be applied to fluidized-bed plants, too.

While the compact simulator technology is striving to further improve its flexibility and effectiveness, many utilities worldwide are already well pleased with its performance, and especially with its affordability.

To probe further

"Portable and Affordable Operator Training Simulators" are discussed by P. Sigari et al. in *IEEE Computer Application in Power,* July 1993, pp. 39–44.

The Society for Computer Simulation (SCS), which held its 11th Annual Simulators Conference, April 10–14, 1994, published the *Proceedings of the 1994 Simulation Multiconference,* complete with papers on simulation of nuclear and fossil power plants; waste management and environmental sciences simulation; and industrial and process simulators (ISBN# 1-56555-071-4, Jaime Olmos and Ariel Sharon, ed.). The 1995 Simulation Multiconference will be held April 9–13, 1995, in Phoenix, Ariz. Contact the society at 619-277-3888.

The Electric Power Research Institute's *Proceedings: Simulators, Modeling and Training Conference,* EPRI TR-103826, includes papers on fossil and nuclear plant simulators, training approaches, and power system simulation presented at the Nov. 16–18, 1993, conference in New Orleans.

For information on fossil plant simulator justification, see the report titled "Justification of Simulators for Fossil Fuel Power Plants," EPRI TR-102690, October 1993.

More information on fossil plant simulator-based training programs is given in "Preliminary Guidelines for Fossil Plant Simulator Training Programs," EPRI TR-101854, July 1993.

EPRI's expert tutoring system is described in "Intelligent Tutoring: Enhancing Simulator Training," EPRI TB-103009, December 1993.

For a discussion of simulator-based training in the natural gas industry, see "Simulator Training Developed for a Gas Distribution System," *Pipe Line Industry,* Vol. 75, no. 2, pp. 23–25, February 1992.

For more information on EPRI compact simulator technology, contact author Roy Fray, EPRI, Box 10412, Palo Alto, Calif. 94303; 415-855-2441. To order EPRI documents, contact the EPRI Distribution Center at 510-934-4212.

About the author

Roy Fray is manager of simulators and training at the Electric Power Research Institute in Palo Alto, Calif. Before joining EPRI, he spent four years at Science Application International Corp., working on reliability, simulation, and support for fossil fuel powergeneration. For 17 years at Pacific Gas and Electric Co., he was responsible for reliability, risk, and simulation analyses support for fossil and nuclear power generation.

profile

M. GEORGE CRAFORD

An adventurous heart often urges this inventor of yellow LEDs along risky routes

TEKLA S. PERRY
Senior Editor

WALK THROUGH HALF A FOOTBALL field's worth of low partitions, filing cabinets, and desks. Note the curved mirrors hanging from the ceiling, the better to view the maze of engineers, technicians, and support staff of the development laboratory. Shrug when you spot the plastic taped over a few of the mirrors to obstruct that view.

Go to the heart of this labyrinth and there find M. George Craford, R&D manager for the optoelectronics division of Hewlett-Packard Co., San Jose, Calif. Sitting in his shirtsleeves at an industrial beige metal desk piled with papers, amid dented bookcases, gym bag in the corner, he does not look like anybody's definition of a star engineer. Appearances are deceiving. "Take a look around during the next few days," advised Nick Holonyak Jr., the John Bardeen professor of electrical and computer engineering and physics at the University of Illinois, Urbana, and the creator of the first LEDs. "Every yellow light-emitting diode you see—that's George's work."

Holonyak sees Craford as an iceberg—showing a small tip but leaving an amazing breadth and depth unseen. Indeed, Craford does prove to be full of surprises—the gym bag, for example. He skips lunch for workouts in HP's basement gym, he said, to get in shape for his next adventure, whatever that might be. His latest was climbing the Grand Teton; others have ranged from parachute jumping to whitewater canoeing.

His biggest adventure, though, has been some 30 years of research into light-emitting diodes.

The call of space

When Craford began his education for a technical career, in the 1950s, LEDs had yet to be invented. It was the adventure of outer space that called to him.

The Iowa farm boy was introduced to science by Illa Podendorf, an author of children's science books and a family friend who kept the young Craford supplied with texts that suited his interests. He dabbled in astronomy and became a member of the American Association of Variable Star Observers. He built rockets. He performed chemistry experiments, one time, he recalls with glee, generating an explosion that cracked a window in his home laboratory. When the time came, in 1957, to pick a college and a major, he decided to pursue space science, and selected the University of Iowa, in Iowa City, because space pioneer James Van Allen was a physics professor there.

As the space race heated up, Craford's interest in space science waned, in spite of a summer job analyzing data returned from the first satellites. He had learned a bit about semiconductors, an emerging field, and Van Allen pointed him toward the solid-state physics program at the University of Illinois, where Craford studied first for a master's degree, then a Ph.D.

The glowing Dewar

For his doctoral thesis, Craford began investigating tunneling effects in Josephson junctions. He had invested several years in that research when Holonyak, a pioneer in visible lasers and light-emitting diodes, left his position at General Electric Co. and joined the Illinois faculty. Craford met him at a seminar, where Holonyak was explaining his work in LEDs. Recalled Craford: "He had a little LED—just a red speck—and he plunged it into a Dewar of liquid nitrogen, and it lit up the whole flask with a bright red light."

Entranced, Craford immediately spoke to his thesis adviser about switching, a fairly unusual proposal, since it involved dropping years of work. "My thesis adviser was good about it; he had been spending less time around the lab lately, and Holonyak was

 0018-9235/95/$4.00©1995 IEEE

CHARLES

building up a group, so he was willing to take me on." Craford believes he persuaded the laser pioneer to accept him; the senior man recalls things differently.

Craford's adviser "was running for U.S. Congress," Holonyak said, "and he told me, 'I've got this good student, but I'm busy with politics, and everything we do someone publishes ahead of me. I can't take good care of him. I'd like you to pick him up.'"

However it happened, Craford's career path was finally set—and the lure of the glowing red Dewar never dimmed.

Holonyak was growing gallium arsenide phosphide and using it successfully to get bright LEDs and lasers. He assigned his new advisee the job of borrowing some high-pressure equipment for experiments with the material. After finding a professor with a pressure chamber he was willing to lend, Craford set up work in the basement of the materials research building. He would carry samples of GaAsP samples from the lab to the materials research basement, cool them in liquid nitrogen, increase the pressure to study the variation of resistivity, and see unexpected effects. "Just cooling some samples would cause the resistance to go up several times. But add pressure, and they would go up several orders of magnitude," Craford said. "We couldn't figure out why."

Eventually, Craford and a co-worker, Greg Stillman, determined that variations in resistance were related not only to pressure but also to light shining on the samples. "When you cooled a sample and then shone the light on it, the resistance went down—way down—and stayed that way for hours or days as long as the sample was kept at low temperature, an effect called persistent photoconductivity." Further research showed that it occurred in samples doped with sulfur but not tellurium. Craford and Stillman each had enough material for a thesis and for a paper published in the *Physical Review.*

The phenomenon seemed to have little practical use, and Craford put it out of his mind, until several years later when researchers at Bell Laboratories found it in gallium aluminum arsenide. "Bell Labs called it the DX Center, which was catchy, studied it intensively, and over time, many papers have been published on it by various groups," Craford said. Holonyak's group's contribution was largely forgotten.

"He doesn't promote himself," Holonyak said of Craford, "and sometimes this troubles me about George; I'd like to get him to be more forward about the fact that he has done something."

Move to Monsanto

After receiving his Ph.D., Craford had several job offers. The most interesting were from Bell Laboratories and the Monsanto Co. Both were working on LEDs, but Monsanto researchers were focusing on gallium arsenide phosphide, Bell researchers on gallium phosphide. Monsanto's research operation was less well-known than Bell Labs', and taking the Monsanto job seemed to be a bit of a risk. But Craford, like his hero—adventurer Richard Burton, who spent years seeking the source of the Nile—has little resistance to choosing the less well-trodden path. Besides, "Gallium phosphide just didn't seem right," said Craford, "but who knew?"

In his early days at Monsanto, Craford experimented with both lasers and LEDs. He focused on LEDs full time when it became clear that the defects he and his group were encountering in growing GaAsP on GaAs substrates would not permit fabrication of competitive lasers.

The breakthrough that allowed Craford and his team to go beyond Holonyak's red LEDs to create very bright orange, yellow, and green LEDs was prompted, ironically, by Bell Labs. A Bell researcher who gave a seminar at Monsanto mentioned the use of nitrogen doping to make indirect semiconductors act more like direct ones. Direct semiconductors are usually better than indirect for LEDs, Craford explained, but the indirect type still has to be used because of band gaps wide enough to give off light in the green, yellow, and orange part of the spectrum. The Bell researcher indicated that the labs had had considerable success with Zn-O doping of gallium phosphide and some success with nitrogen doping of gallium phosphide. Bell Labs, however, had published early experimental work suggesting that nitrogen did not improve GaAsP LEDs.

Nonetheless, Craford believed in the promise of nitrogen doping rather than the published results. "We decided that we could grow better crystal and the experiment would work for us," he said. A small team of people at Monsanto did make it work. Today, some 25 years later, these nitrogen-doped GaAsP LEDs still form a significant proportion—some 5–10 billion—of the 20–30 billion LEDs sold annually in the world today.

Again, Holonyak complains, Craford didn't toot his own horn. "When George published the work, he put the names of the guys he had growing crystals and putting the things together ahead of his name." His peers, however, have recognized Craford as the creative force behind yellow LEDs, and he was recently made a member of the National Academy of Engineering to honor this work.

Craford recalls that the new palette of LED colors took some time to catch on. "The initial reaction" he said, "was, 'Wow, that's great, but our customers are very happy with red LEDs. Who needs other colors?' "

Westward ho!

After the LED work was published, a Monsanto reorganization bumped Craford up from the lab bench to manager of advanced technology. One of his first tasks was to select researchers to be laid off. He

Vital statistics

Name: Magnus George Craford
Date of birth: Dec. 29, 1938
Birthplace: Sioux City, Iowa
Height: 185 cm
Family: wife, Carol; two adult sons, David and Stephen
Education: BA in physics, University of Iowa, 1961; MS and Ph.D. in physics, University of Illinois, 1963 and 1967
First job: weeding soybean fields
First electronics job: analyzing satellite data from space
Patents: about 10
People most respected: explorer and adventurer Sir Richard Burton, photographer Galen Rowell, Nobel-prize winner John Bardeen, LED pioneer Nick Holonyak Jr.
Most recent book read: *The Charm School*
Favorite book: *Day of the Jackal*
Favorite periodicals: *Scientific American, Sports Illustrated, National Geographic, Business Week*
Favorite music: string quartets
Favorite composers: Mozart, Beethoven
Computer: "I don't use one."
Favorite TV show: "NYPD Blue"
Favorite food: Thai, Chinese
Favorite restaurant: dining room at San Francisco's Ritz Carlton Hotel
Favorite movies: *Bridge on the River Kwai, Butch Cassidy and the Sundance Kid, The Lion in Winter*
Leisure activity: hiking, walking, snow skiing, bicycling, tennis, and, most recently, technical mountain climbing.
Car: Sable Wagon (a company car)
Pet peeves: "People that work for me who don't come to me with little problems, which fester and turn into big ones."
Organizational memberships: IEEE, Society for Information Display
Favorite awards: National Academy of Engineering, IEEE Fellow, IEEE Morris N. Liebmann Memorial Award; but "everything you do is a team thing, so I have mixed feelings about awards."

recalls this as one of the toughest jobs of his life, but subsequently found that he liked management. "You have more variety; you have more things that you are semicompetent in, though you pay the price of becoming a lot less competent in any one thing," he told *IEEE Spectrum*.

Soon, in 1974, he was bumped up again to technology director, and moved from Monsanto's corporate headquarters in St. Louis to its electronics division headquarters, in Palo Alto, Calif. Craford was responsible for research groups developing technology for three divisions in Palo Alto, St. Louis, and St. Peters, Mo. One dealt with compound semiconductors, another with LEDs, and the third with silicon materials. He held the post until 1979.

Even as a manager, he remained a "scientist to the teeth," said David Russell, Monsanto's director of marketing during Craford's tenure as technology director. "He is a pure intellectual scientist to a fault for an old peddler like me."

Though always the scientist, Craford also has a reputation for relating well to people. "George is able to express complicated technical issues in a way that all of us can understand," said James Leising, product development manager for HP's optoelectronics division. Leising recalled that when he was production engineering manager, a position that occasionally put him in conflict with the research group, "George and I were always able to work out the conflicts and walk away friends. That wasn't always the case with others in his position." One time, in particular, Leising recalled, Craford convinced the production group of the need for precise control of its processes by graphically demonstrating the intricacies of the way semiconductor crystals fit upon one another.

As an executive, Craford takes credit for no individual achievements at Monsanto during that time, but said, "I was proud of the fact that, somehow, we managed to be worldwide competitors in all our businesses." Even so, Monsanto decided to sell off its optoelectronics business and offered Craford a job back in St. Louis, where he would have been in charge of research and development in the company's silicon business.

Craford thought about this offer long and hard. He liked Monsanto; he had a challenging and important job, complete with a big office, oak furniture, a private conference room, and a full-time administrative assistant. But moving back to St. Louis would end his romance with those tiny semiconductor lights that could make a Dewar glow; and when the time came, he just couldn't do it.

Instead, he did the Silicon Valley walk: across the street to the nearest competitor, in this case, Hewlett-Packard Co. The only job it could find that would let him work with LEDs was a big step down from technology director—a position as R&D section manager, directing fewer than 20 people. This meant a cut in salary and perks, but Craford took it.

The culture was different, to say the least. No more fancy office and private conference room; at HP Craford gets only "a cubby, a tin desk, and a tin chair." And, he told *Spectrum*, "I love it." He found the HP culture to be less political than Monsanto's, and believes that the lack of closed offices promotes collaboration. At HP, he interacts more with engineers, and there is a greater sense that the whole group is pulling together. It is more open and communicative—it has to be, with most engineers' desks merely 1.5 meters apart. "I like the whole style of the place," he declared.

'Every yellow light-emitting diode you see—that's George's work'

Now he has moved up, to R&D manager of HP's optoelectronics division, with a larger group of engineers under him. (He still has the cubby and metal desk, however.) As a manager, Craford sees his role as building teams, and judging which kinds of projects are worth focusing on. "I do a reasonably good job of staying on the path between being too conservative and too blue sky," he told *Spectrum*. "It would be a bad thing for an R&D manager to say that every project we've done has been successful, because then you're not taking enough chances; however, we do have to generate enough income for the group on what we sell to stay profitable."

Said Fred Kish, HP R&D project manager under Craford: "We have embarked upon some new areas of research that, to some people, may have been questionable risks, but George was willing to try."

Craford walks that path between conservatism and risk in his personal life as well,although some people might not believe it, given his penchant for adventurous sports: skydiving, whitewater canoeing, marathon running, and rock climbing. These are measured risks, according to Craford: "The Grand Teton is a serious mountain, but my son and I took a rock-climbing course, and we went up with a guy who is an expert, so it seemed like a manageable risk."

Holonyak recalls an occasion when a piece of crystal officially confined to the Monsanto laboratory was handed to him by Craford on the grounds that an experiment Holonyak was attempting was important. Craford "could have gotten fired for that, but he was willing to gamble."

Craford is also known as being an irrepressible asker of questions.

"His methods of asking questions and looking at problems brings people in the group to a higher level of thinking, reasoning, and problem-solving," Kish said.

Holonyak described Craford as "the only man I can tolerate asking me question after question, because he is really trying to understand."

Craford's group at HP has done work on a variety of materials over the past 15 years, including gallium aluminum arsenide for high-brightness red LEDs and, more recently, aluminum gallium indium phosphide for high-brightness orange and yellow LEDs. The latest generation of LEDs, Craford said, could replace incandescent lights in many applications. One use is for exterior lighting on automobiles, where the long life and small size of LEDs permit car designers to combine lower assembly costs with more unusual styling. Traffic signals and large-area display signs are other emerging applications. He is proud that his group's work has enabled HP to compete with Japanese LED manufacturers and hold its place as one of the largest sellers of visible-light LEDs in the world.

Craford has not stopped loving the magic of LEDs. "Seeing them out and used continues to be fun," he told *Spectrum*. "When I went to Japan and saw the LEDs on the Shinkansen [high-speed train], that was a thrill." He expects LEDs to go on challenging other forms of lighting and said, "I still hope to see the day when LEDs will illuminate not just a Dewar but a room." ◆

Finding the right people to guide you can tilt the scales in favor of career success

A MENTOR

THE DICTIONARY DEFINES A mentor as a wise and trusted counselor or teacher. At every stage of our lives, every one of us depends upon such people. When we are young, our mentors are most often our mothers and fathers, but sometimes they may be older brothers or sisters, or aunts or uncles. As we mature, other mentors enter the picture: teachers, coaches, guidance counselors, priests, rabbis, and professors, to name a few.

Our engineering lives are no different. Mentors are needed at work no less than in other areas.

Persons to prize

In fact, by finding and cultivating suitable people as mentors, you can tilt the scales in favor of a successful career. People who are well placed and well regarded in your organization can guide you to the top and introduce you to the inner circle of executives—the people who decide who moves up and who doesn't. Mentors may also prompt you to develop the technical and business skills you need to advance. Conversely, a mentor who is not strategically positioned or respected in the organization or whose guidance is poor can damage your prospects. The challenge is to uncover likely candidates and get on good terms with them.

The right kind of mentor will sponsor you, watch out for you, polish your act, and help you get the more testing (hence more rewarding) job assignments. Tough assignments are a chance to prove you are ready to move up. It is this active type of sponsorship that will see to it you stand out from the crowd.

Good coaching and mentoring take different forms. For example, suggestions about dealing with a domineering supervisor or about averting technical failures and recovering from them could give you a leg up on hard-to-handle problems. A good mentor will also stand up for you when need be and defend your actions—if he or she agreed with them in the first place. Mentors can deflect blame from you. They can be a shield in times of trouble. Always, though, a good mentor is a good coach, forever challenging you, inspiring you, and demanding that you do your best.

By developing good relationships with powerful mentors, you absorb some of their power, for you are sending a signal that you belong to a powerful team. You may become privy to inside information or gain new organizational influence with which to slice your way through the red tape and bureaucracy that entangle most organizations.

Finding a guide

Above all, look for mentors outside your own department. Choosing someone inside it may be quick and easy but will cause too many problems, above all jealousy, and could alienate other members of your group.

Discovering and cultivating a good mentor is not easy. It can also take quite a long time. Possible candidates include any senior person with the power to influence your career for the better. You should pick someone who appears to you to be a success and whom you would like to emulate. Look for someone who excites you and gets you going and with whom you feel comfortable and compatible.

You and your mentors should have similar views about company strategies and success in the corporate world. They should be people with whom you can share triumphs, defeats, and new ideas, receiving in turn guidance, a nonjudgmental audience, and constructive criticism. You should respect and value your mentor's honest opinion, and find your intelligence and capabilities respected and valued in turn.

Naturally, people do not walk around with badges identifying them as future mentors. But

Adapted from Chapter 7 of *Career Advancement and Survival for Engineers* by John A. Hoschette (with permission, John Wiley & Sons [800-225-5945], 1994, 200 pp., $39.95 cloth, $15.95 paper). For earlier excerpts, see *IEEE Spectrum*, November 1994, pp. 96–99, and December 1994, pp. 42–44.

JOHN A. HOSCHETTE
Loral Infrared and Imaging Systems

those with this potential do throw out hints. When you are working with senior people, do they take the time to explain everything you should know? Do they expend the effort to make sure you get the assignment right? Do you find yourself adopting similar approaches to problems?

Further, is there a chemistry between you and certain senior people? Do you take pleasure in analyzing tough problems with them? Do any of them like your style and give you compliments on your work? Do you have the same sort of outside interests?

Once you have found suitable candidates, woo they are directing. Discover which are their pet projects and get involved. Let possible mentors know how much you prize their opinion. You might even ask them if they would mind if you viewed them in the role of mentor.

But don't get carried away. Be enterprising about finding mentors and keeping them, but also be cautious. Aggressiveness can provoke resentment among your co-workers and brand you as a brown nose or apple polisher. Nor do you want to become a mere gofer or yes-man—dealings with mentors must be equitable. Persons who use you for their benefit alone, abuse you. Look for true mentors.

IN HAND...

KEN HAMILTON

them. This type of interaction has to be carefully nurtured. You must be prepared to sink a good deal of time and effort into developing the relationship. Share lunch hours with likely prospects. From time to time, stop by their office to ask for an opinion about whatever you are working on.

Pass their offices on your way out the door at night. Volunteer your assistance with projects

Know, too, that differences in age matter. Anyone who is less than eight years your senior might be more like a close friend than a mentor. A difference of eight to 15 years is best; past 15 years, you may end up with a quasi–parent-child relationship.

Don't rely on just one mentor; if he or she leaves the company, you are stranded. In any case, no one person can supply all the guidance

you need. Engineers ought to have at least one technical mentor, plus others with business and political acumen.

It's obvious that you will need technical guidance. But why bother with the others? Well, you will also want to avoid working on a project that may be a dead end as far as company management is concerned. A smart business mentor can forewarn you.

Use and misuse of mentors

Mentors can be over- and under-used. If you search them out for their advice on every conceivable problem, they will soon start thinking of you as indecisive or unable to do your own work. On the other hand, if you go to your mentors only after you have solved a problem, you miss out on their wisdom. So what's the best time to ask for their help? It depends on the specifics of your relationships with them, but in general they may be categorized as times of uncertainty.

Times of trouble are probably the most obvious occasions for consulting mentors. Still, don't just dump your problems in their lap. Come to the discussion with possible solutions in mind so you can list your options and highlight the pros and cons. Ask for advice as to what your options are. And do be ready to act on the guidance you receive and report back on your progress, to show your mentors that you take their advice seriously.

Mentors are also useful as a sounding board for new ideas and new approaches to problems. Selling such an idea to others is easier when your mentor, too, is pushing for it. Moreover, the kind of person who makes an appropriate mentor has years of experience and should be able to assess your chances. After you present your ideas, let the other person make recommendations—and then put them into effect. You may not see the need for the changes your mentors suggest, but they may know about problems or opportunities hidden from you. And again, nothing is more disheartening than suggesting a course of action that is never even tried.

The start of a project (not to mention its middle and end) is an excellent time to consult with your mentors. Meet with them and go over your plans—how you have set things up, the activities you envision, the obstacles you foresee. Later, about halfway through the project, discuss the problems you are in fact encountering and the steps you are taking to resolve them. Ask how they think the project is faring. Get them to find out how other senior people view its progress and how to change any derogatory perceptions. Mentors can be a great resource for uncovering and overcoming barriers within your organization.

Also seek out your mentor's guidance when a project is ending. What is the best way to conclude it and present the results? How can you enlighten management on the fine job you did? What steps should you take to choose your next project? Do your mentors have any ideas or recommendations? Can they sponsor you on another project? Who are the people you must reach, and how?

Any time you feel pigeonholed or as if you are stagnating is another good occasion to ask for advice. Good mentors will be able to enlighten you about things going on behind the scenes but hidden from you. They may be able to chat with your supervisor or others in the know and find out information denied you.

Finally, when you have failed on a project and need to recover, never be afraid to ask for help. Some people, preferring the image of a superman, react to failure by trying to hide it. Yet failure need not be a career limitation. In fact, good advisors can show you how to rise above it and even turn it into an opportunity for advancement. Nothing impresses management more than a willingness after a failure to seek out the help of others, identify solutions, and implement them.

For women, a word of caution

Men dominate engineering. A woman is more likely to have a man than another woman as her mentor. A good male mentor should challenge you and urge you to make bold strides rather than timid little steps. He should give you the same advice he would give a man.

Alas, a true mentoring relationship between a male mentor and female subordinate—or a female mentor and male subordinate—is extremely hard to develop and maintain. The different interests of men and women, the jealousy of spouses or significant others, and the link between power and sex are dangers that are all too prone to prevent the course of the mentoring relationship from running smoothly.

Women with a male mentor should be sure to notice if the relationship appears to be modulating into a more than friendly key—and switch to someone else if this starts to happen. An emotional or sexual involvement diverts your energies from the primary goal, career advancement. That kind of involvement can quickly ruin both your mentor's career and yours.

So it may be worth a special effort for women to find women as mentors. Organizations off limits to men, such as the Society of Women Engineers, aim to give their members an opportunity to network and so are excellent places to find mentors. Women in this role can provide tips on the specific problems their sex faces in engineering: the "good old boys" barriers, sexism, and sexual harassment. Indeed, for a woman engineer, several female mentors are an absolute necessity.

Many people are squeamish about actively developing a mentor. Someone else, they feel, should just choose to guide them. It rarely happens. Meanwhile, if you can choose a spouse, why can't you pick a mentor? You have so little to lose and such a lot to gain.

Homework

1. Make a list of several people in your company who you think might make good mentors for you. Pick one and approach him or her about some problem you have and ask for guidance. Watch the reaction? Is it what you need in a mentor?

2. Identify a good technical mentor. How about a good business-oriented mentor?

3. Identify organizations outside your company—for example, the Institute of Electrical and Electronic Engineers—that might be sources of mentors.

4. For female engineers, contact your local chapter of the Society of Women Engineers. Can you think of other organizations that might be a good source of mentors?

5. Topics for discussion:

- Do mentors last forever?
- How should mentors change as your career advances?
- What are good qualities in a mentor?

To probe further

The IEEE's U.S. Activities' Career Maintenance and Development Committee and the Boston Section, with support from the Institute's Professional Activities Committees for Engineers (PACE), are sponsoring career seminars featuring John A. Hoschette. The first seminar will be held on Monday, March 27. Hoschette is also scheduled to speak at the Boston Section's monthly meeting on April 27. Contact the Boston Section on the Internet at sec.boston@ieee.org for details of the time and place.

About the author

John A. Hoschette is a staff engineer with Loral Infrared and Imaging Systems, in Lexington, Mass. He worked for the last 18 years in all phases of engineering projects, including the technical direction of several multimillion-dollar programs. This article is adapted from his book, *Career Advancement and Survival for Engineers*, which is based on course material he developed at his company on career development for engineers. He can be reached on the Internet at john_hoschette@liris.loral.com.

technically speaking

Slandered by Hamlet!

KEVIN SELF

Our interest in the reputation of engineers led us to reexamine some of the works of writer William Shakespeare, a major figure in English literature but also, it seems, one of the earliest detractors of the engineering profession.

Many are familiar with the phrase "hoist by his own petard," which he used in his play *Hamlet*. Common wisdom has it that a petard (or "petar," as Shakespeare wrote it) is a synonym for bootstrap, rope, or even *derrière*, but its true meaning is quite different. The second edition of *Webster's New Twentieth Century Dictionary* defines a petard as "a metal cone filled with explosives; in ancient warfare it was fastened to walls and gates and exploded to force an opening." According to *The Annotated Shakespeare, Vol. III* (Clarkson N. Potter, New York), "hoist" in those times meant to blow up or explode, rather than our modern meaning of lift. But according to Webster's, the correct interpretation, is "caught in one's own trap; involved in danger meant for others."

We take umbrage, though, at how Shakespeare employed this line. It occurs during a conversation between Hamlet and his mother, as he discusses how he will outwit his uncle, who is plotting to have him murdered. The full line from the play, unknown to most of us, is "For 'tis the sport to have the enginer [*sic*] hoist with his own petar."

Shakespeare's suggestion that it would be "sport" to see an engineer propelled skyward by a defective device leads us to suspect that he harbored a deep-seated resentment of engineers. Unfortunately, however, we were unable to contact Mr. Shakespeare and get him to elaborate on this slight. We take some small measure of comfort from knowing that he was much more abusive of tax collectors and lawyers in his plays.

To B or not to b?

Our musings on the correct use of the metric system have stirred some of our readers to put pen to paper. Two letters queried the correct way to abbreviate bit and byte.

Reader Michael McDonald, writing from Tokyo, complained about the lack of a standard for referring to multiple bytes or bits. When he proposed this to an IBM on-line forum, he received a variety of comments, the gist of which was that the scientific community prefers 10 kilobytes or 10 kB, whereas at IBM, one should write 10KB if a kilobyte is 1024 bytes, and 10 KB if it's 1000 bytes, but never 10K bytes (with the space between K and b). Simple enough?

A perusal of a number of data books and manuals shows the situation is anything but simple, and rarely consistent, with both upper- and lower-case Ks and with different spacings between the quantity and unit symbol. A typical instance appears in the *386SX Microprocessor Programmers Reference Manual* (Intel, 1989), where memory designations of 64K (space) bytes and 64 (space) Kbytes are mixed on the same page. Yet another blow to intra-company consistency is seen in the *Intel 1994 Flash Memory: Volume II* data book, where a reference to "64-Kbyte blocks" is found. The *Toshiba 1992 Static RAM Data Book* sidesteps ambiguity by wordy descriptions such as "8192 words by 8 bits."

The root of the problem is the dual use of the metric prefix "kilo-" to mean 1024 as well as 1000. Two *IEEE Spectrum* editors, Michael J. Riezenman and Linda Geppert, have addressed this problem afresh and developed a set of guidelines for *Spectrum's* internal use in dealing with such multibyte mania. In an attempt to clear up this bewildering bit business once and for all, we reprint their findings.

They recommend that we:

- Employ an upper-case K to indicate 1024, thus avoiding confusion with the lower-case letter, which will always mean 1000.
- When dealing with powers of 2, always omit the space between the number and the symbol, and (in keeping with standard SI practice) never put a space between a prefix and the symbol it modifies. Thus 1 048 576 bytes is 1MB, but 1 000 000 bytes per second is 1 MB/s.
- Never hyphenate an expression meant to be a power of 2—for example, describe a memory with a capacity of 131 072 bits as a 128Kb device, not as a 128-Kb device.
- Never spell out prefixes—kilo- and mega-, say—when they are meant to be powers of 2.
- And (again, as in standard SI practice) never mix abbreviations with spelled-out terms. That is, never write Kbit or Mbyte; instead, use Kb and MB.

But whenever kilo- and mega- mean 1000 and 1 000 000, respectively, standard metric practice applies—namely, the quantity is separate from the unit symbol.

A related point has perplexed reader Allan Mossberg of Green Valley, Ariz.—when is it correct to capitalize the B in bits, bytes, and bels, and when not? Here there does appear to be a standard.

In general engineering usage, a lower-case b is used to indicate bits, whereas an upper-case B indicates bytes. *Spectrum's* policy, supported by the *IBM Dictionary of Computing* (McGraw-Hill, New York, 1993), is to use Kb for 1024 bits, KB for 1024 bytes, and so on. But because b by itself looks odd, we spell it out as bit or bits.

The word "bel," with a lower case b, is defined by the *IEEE Standard Dictionary of Electrical and Electronics Terms* as "the fundamental division of a logarithmic scale for expressing the ratio of two amounts of power, the number of bels denoting such a ratio being the logarithm to the base 10 of this ratio." It follows that the decibel is one-tenth of a bel. *Webster's New Twentieth Century Dictionary* explains that the unit was named after the inventor Alexander Graham Bell. In keeping with the standard metric practice of capitalizing a unit symbol but lower-casing units named for persons, bel is not capitalized but the B in dB is.

Correcting current

Kudos go to readers who spotted the misuse of the phrase "current flow" on p.77 of the December 1994 *Spectrum*. The term should be "flow of charge." Reader Gregory Deal correctly noted that " 'flow of current should be avoided, as it means literally 'flow of flow of charge'."

For reader Larry Wofford our choice of terminology here resurrected unpleasant memories. "My high school physics teacher would have reduced me to a mere grease spot on the floor had I spoken of current flow," he remembers. "I can hear him screaming now about current being the rate of flow of charge..."

Technically Speaking is intended as a commentary on the use and misuse of technical language and culture. Readers are invited to send their comments or concerns by mail to Technically Speaking at *IEEE Spectrum*, or by e-mail to klself@mcimail.com. Please indicate the city, state, and country you are writing from, as well as IEEE affiliation, if any.

Contributing editor Kevin Self (M) surveys the etymological world from his workbench at Dallas Semiconductor Corp., in Dallas, Texas.

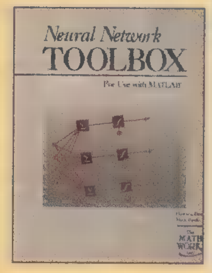
Consultant: Anne Eisenberg, Polytechnic University

software reviews

Neural networks made easy

PHILIP KOHN

Neural Networks Toolbox.
For use with Matlab. Runs on Unix-based workstations, 386- and 486-based PCs and Macintosh systems, and VAX VMS. Matlab requires 8MB of RAM and 8MB of hard drive (MS-Windows and Macintosh); 16MB RAM and 20-MB hard drive (Unix and VMS). A swap space of 64MB is recommended for Unix. US $195 (Neural Network Toolbox), $495 (Matlab), and $495 (Simulink), all for Windows and the Macintosh. Contact vendor for academic discounts.



Matlab is a language and system for solving problems in applied mathematics by applying the appropriate software toolbox. The latest toolbox makes it easy to build and train many types of artificial neural networks. Its manual, source files, and examples soon give their user a good grasp of this type of circuitry.

Matlab consists of a large and growing number of fast numeric and visualization functions that operate on vectors and matrices and run on Unix (X windows), 386/486 (Windows), and Macintosh. For this review, a SparcStation 2 and a 486 clone were used. Installation under PC Windows and Sun Unix went smoothly.

Of the several general-purpose systems that handle mathematical manipulation, Matlab is the best suited for working with neural net algorithms. It, Macsyma, Maple, and Mathematica each have their own strengths, but over time, as often happens with large software systems, they have come to include more of each other's features. For example, Matlab has lacked the symbolic manipulation functions of the other three systems but recently made good by incorporating Maple as a toolbox. If this trend continues, most mathematical systems will eventually have the same features and differ mainly in how well the original structure supports all the extensions.

Matlab is based on matrix and vector functions and adept at executing them. The two strengths play to the needs of most neural net algorithms, which are readily described by matrix equations and often computationally demanding. The algorithms can tackle many classical problems, such as optimization, categorization, interpolation, probability estimation, forecasting, and pattern recognition.

Neural networks are often a part of a larger algorithm or mathematical system, and should ideally be simple to embed in such applications as financial prediction or robotics. When the system can be drawn as an interconnected collection of processing blocks, an optional Matlab package, Simulink, simplifies the task of building it, too: first select the processing modules (neural network or other) from menus and then use the mouse to guide the flow of data between blocks. These block diagrams can be compiled into a C language source, greatly increasing efficiency.

The neural network toolbox has a user's manual, on-line documentation, and an impressive number of very small functions written in Matlab's language. These functions may be anywhere from 16 to 150 lines long (50 lines is the average) and start with HELP command documentation. They owe their brevity and straightforwardness to that fact that most neural networks are concisely described by matrix equations. Because of the nature of matrix equations, the same equation can process a single vector or a whole matrix of vectors in one batch. Sparse matrices can be used for certain categorization problems (where the target vectors may be mostly 0s) and for certain vector quantized inputs (where the input unit closest to an input vector is active).

Having source code for the complete toolbox makes it simple to tinker with working examples—an excellent way of learning about neural nets and how to customize them. In addition to functions that run and train different architectures, there are visualization functions (such as error surface plots and Hinton diagrams) and scripts that demonstrate specific pitfalls or applications.

Meanwhile, too many architectures are being developed too quickly for any current system to include them all. The Matlab toolbox concentrates on batch update, where weights of interconnections between processing blocks are changed after processing all the data, and has very little support for on-line or stochastic training. However, it was easy to modify the back propagation training function to handle any batch size. Also, there are no pruning (or regularization functions that give an advantage to simpler networks), constructive, composite (multiple experts), or semantic network architectures.

The Matlab language has the no-nonsense simplicity of Basic (no declarations, for instance) and the compactness of APL (one operator can have a number of meanings, depending on whether the arguments are vectors or matrices, and so on). Because each function call performs many calculations, matrix-oriented operations shrink the language overhead per calculation. Still, it does take a while to master all the tricks involved in using a matrix equation instead of loops and flow control statements. Also, C programmers will have to overcome their instinct to count from 0, since Matlab counts from 1.

Matlab is not hard to integrate into larger systems. It comes with C and Fortran function libraries for accessing Matlab data files. Windows dynamic data exchange (DDE) is supported allowing a Matlab script to open one's favorite spreadsheet, grab some data, operate on it, and send it back. Under Windows, Unix, or VMS, it can be used as a background "engine." C or Fortran programs can send any Matlab command by a call to a simple function. A package of graphical user-interface functions all work the same under X Windows, MS-Windows, and Macintosh and include all the usual widgets (submenus, buttons, editable fields, sliders).

The first 10 chapters of the manual are a well-organized introduction to many architectures, including Widrow-Hoff (delta), perceptron, linear, back propagation (momentum, Levenberg-Marquardt), radial basis functions, Hebbian, instar and outstar, Kohonen, competitive, vector quantization, Elman, and Hopfield. Chapter 11 describes a set of application scripts, including prediction, noise cancellation, amplitude detection, and character recognition. In general, the manual has a minimum of theory and equations, a maximum of diagrams, graphs, demo programs, and straight talk about the limitations and tuning of free parameters. Many common difficulties in training, like too high or low a learning rate and over- or underfitting, are demonstrated, complete with scripts that draw all the graphs in the text.

Together, the manual and toolbox make a practical vehicle for interactively exploring how to apply neural networks to real problems. The manual's small index is the weakest element, but the lack is made good by the LOOKFOR command, which (slowly) searches all the HELP text for key words. Using this and the HELP command eliminates the need to constantly look up functions and arguments.

Such a diversity of techniques exists that no system is mature enough to handle them all. However, an environment like Matlab, with its many tool kits, has advantages for the researcher designing new neural architectures and for the developer applying an existing neural net design to anything from forecasting to artificial intelligence.

The technical support from The MathWorks was excellent, whether by phone, e-mail (service@mathworks.com), or network news (comp.soft-sys.matlab). The one bug report I submitted (a cosmetic bug related to Xlib in the Unix version) was promptly explained. Several MathWorks employees answer many of the questions that come up in the news group, including requests for new features.

I posted a request on the Internet for feedback from users of the neural network toolbox. All the responses were quite positive, and there was not a single negative comment. *Contact: The MathWorks Inc., 24 Prime Park Way, Natick, MA 01760-1500; 508-653-1415; fax, 508-653-6284; or* **circle 110.**

Philip Kohn is senior software engineer at the International Computer Sciences Institute in Berkeley, Calif. His e-mail address is kohn@icsi.berkeley.edu.

For writing your next paper

MARK S. MIROTZNIK

Scientific word-processing takes a step in the right direction with Scientific WorkPlace by TCI Software Research. If you are like me, you have admired from afar the quality of scientific documents produced by the TEX typesetting software. To date, however, I have been unwilling to exchange my trusty what-you-see-is-what-you-get (WYSIWYG) word processor for the complicated set of commands used to generate a TEX document.

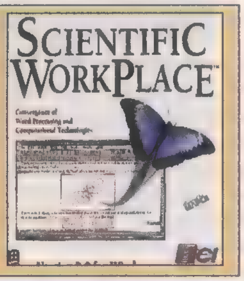
Scientific WorkPlace is exactly what I was looking for to bridge the gap. Documents are entered in their entirety through a well-thought-out interface and thereafter formatted and typeset automatically in the TEX typesetting language. The result gives you TEX typesetting quality without the hassle of learning all those complicated codes.

At the core of Scientific WorkPlace is a free-form interface that separates the content of the document from the appearance—quite the opposite from WYSIWYG. With this interface, the document's text, graphics, and equations can be entered without paying attention to font selection, spacing, alignment, or other format-related concerns. All those choices are made earlier, by selecting from a wide variety of predefined formats (the styles of nearly all the major scientific journals are included) or by creating your own style using the style editor. Once text, graphics, and tables are entered, formatting and typesetting are implemented automatically by Scientific WorkPlace.

For greater appeal to the scientist, the programmers have integrated into their product's environment a nearly complete version of the mathematical software package Maple. Equations can be entered and then solved, symbolically or numerically, using Maple's powerful capabilities. All of the graphical abilities of Maple, including a wide variety of two- and three-dimensional plots, are also available to the user.

To test Scientific WorkPlace, I attempted to write an *IEEE Transactions* article without ever leaving the WorkPlace environment. While I could not quite reach this goal, I did succeed in producing all the computations, generating many of the graphs, and of course, entering all the text from within Scientific WorkPlace. However, I did need to import some illustrative drawings (which the WorkPlace did easily) and one plot from other programs (a 2-D plot with error bars that proved beyond the WorkPlace). The document when finally entered was automatically formatted and typeset using the *IEEE Transactions* format style and was ready for submission.

Scientific WorkPlace. *The program requires an Intel 80386 or 80486 computer with 4MB RAM minimum (8M B preferable) and 30MB of hard disk space, and Microsoft Windows version 3.1 or later. US $595. A student edition also available.*



Be in no rush to throw out your old WYSIWYG word processor quite yet, however. I found mine was much faster for those documents that needed neither Maple nor advanced typesetting features.

Installation is automatic, and the manuals are well written. For this review, I ran the program on a 66-MHz, 486-based PC with 16MB of RAM under Microsoft Windows version 3.1. While Scientific WorkPlace strictly requires only 4MB of RAM, I do not suggest that anyone try to run the program with less than 8MB. In summary, I found the program a novel idea in scientific word processing. *Contact: TCI Software Research, 1190 Foster Road, Las Cruces, NM, 88001-3739; 505-522-4600; fax, 505-522-0116, or* **circle 111.**

Mark S. Mirotznik is an assistant professor in the department of electrical engineering, the Catholic University of America. His e-mail address is mirotz@pluto.ee.cua.edu.

recent software

Hipparchus version 2.2. A C language function library for the development of tools for analysis of geographical data. Applications to date include radio propagation and large-scale seismic studies, satellite iceberg tracking, marine navigation, and petroleum exploration. Available for 16-bit MS-DOS and MS Windows, Windows NT, OS/2 2.1, several workstations, and Digital Equipment's VAX VMS. US $475 (one user) and up. *Contact: Geodyssey Ltd., 815 Eighth Ave., S.W., Suite 500, Calgary, AB, Canada T2P 3P2; 403-234-9848; fax, 403-266-7117; or* **circle 112.**

Extend. For modeling and simulation of continuous and discrete event systems ($695); **Extend+BPR** for business process analysis ($990); **Extend+manufacturing** for modeling of industrial operations ($990). Runs on Macintosh computers. *Contact: Imagine That Inc., 6830 Via Del Oro, Suite 230, San Jose, CA 95119; 408-365-0305; fax, 408-629-1251; or* **circle 113.**

XFDTD. For finite-difference, time-domain transient electromagnetic analysis. Applicable to conductors and a wide variety of dielectric and magnetic materials. Mesh size typically one-tenth of the shortest wavelength of interest. Menu controlled. Available for several Unix platforms and for Intel 486/Pentium. *Contact: Remcom Inc., Calder Square, Box 10023, State College, PA 16805-0023; 814-353-2986; or* **circle 114.**

The Product Profiles advertising section provides a monthly, distinctive focus on both new and commercially established products and services. They offer practical solutions for engineering and scientific professionals in today's fast-paced, rapidly changing high-tech environment.

Circle the corresponding number on the Reader Service Card.

EEs' tools & toys

Digital scope takes the lead in speed

Students of advanced digital circuitry, pulsed lasers, electrostatic discharges, and other high-speed phenomena are never satisfied. No matter how fast their measuring equipment, they always want it to be faster. Nevertheless, even these scientists and engineers will find it tough not to be impressed by the performance of the Model 9362 digital storage oscilloscope from LeCroy Corp. The scope can acquire single-shot events at a blazing 10 gigasamples per second, making it the fastest such instrument in the world.

▲ Capable of acquiring signals at a blazing 10 gigasamples per second, LeCroy's Model 9362 digital storage oscilloscope can also act as a 100-megasample-per-second instrument, thus increasing its record length from 1000 points to 20 000.

Unlike some extremely high-speed scopes, which have only a single-shot mode, the new LeCroy unit also offers a random interleaved sampling (RIS) mode for repetitive signals. In this mode, the scope has a bandwidth of 1.5 GHz. (In the single-shot mode, that bandwidth is in effect halved by the track-and-hold circuits in the high-speed digitizer.)

In point of fact, the 9362 is two instruments in one: a 10-gigasample-per-second scope with a 1000-point record length, and a 100-megasample-per-second scope with a record length of 20 000 points. Its users can, as a result, look over a longish time interval at a moderate sampling rate and then scrutinize a shorter interval of interest at a high sampling rate, thus getting an overall sense of how a circuit or device is behaving before zooming in close to see exactly what is going on.

In addition to its raw power, the 9362 has a host of convenient features. Among them are a repertoire of 32 automatic measurements (rise time, frequency, root-mean-square value, overshoot, and so on); extensive waveform math capability; and several smart trigger modes, including an unusual dropout mode that reacts when a trigger or pattern signal drops out for longer than a specified time.

Options include a disk drive for storing instrument setups, waveforms, screen graphics, and pass/fail templates; a thermal printer for making hard copies of screen images; and a fast Fourier transform add-on to the math package.

The 9362 is priced at US $14 990. Delivery takes eight weeks. *Contact: LeCroy Corp., 700 Chestnut Ridge Rd., Chestnut Ridge, NY 10977-6499; 914-578-6020. European readers may prefer to call LeCroy's office in Heidelberg, Germany, (49+6221) 831-001; or* **circle 100.**

general interest

Patent information on disk

Engineers and others who need to follow emerging technological developments worldwide may benefit from one or more of the 32 electronic newsletters published monthly by MicroPatent. The company puts out more than 10 newsletters of direct interest to electrical and electronics engineers—five on electronics, three on computers, and one each on energy, lasers, fiber optics, and telecommunications. Still others cover such fields as automobiles, textiles, pharmaceuticals, food technology, and medical devices.

Called World Patent Alerts (WPAs), the newsletters cover patents from all over the world, presenting information in a fully searchable form. The products are distributed on 90-mm floppy disks, which the company claims are dramatically easier to use than the U.S. Patent and Trademark Office's *Official Gazette*, a weekly document the size of a telephone book.

WPA comes with Searchfast software with which users may search for patents using any combination of criteria, including issue date, patent number, classification, owner, inventor, and title or abstract text. By adding each new issue to previous issues, users can build complete back files for their industries.

The annual subscription rate for a WPA is $295 for the first newsletter and $150 for each additional one. *Contact: MicroPatent, 250 Dodge Ave., East Haven, CT 06512-3358; 203-466-5055; toll-free, 800-648-6787; fax, 203-466-5054; or* **circle 101.**

automation

Low-cost PLCs

The never-ceasing effort to add value to products without adding consequentially to their cost has been facilitated (at least for the makers and users of automatic machinery) by Allen-Bradley Co.'s introduction of its MicroLogix 1000 family of programmable logic controllers (PLCs). Aimed at applications with fewer than 32 input-output ports, the new controllers are small and fast, as well as inexpensive.

The smallest member of the MicroLogix 1000 family measures a compact 120 by 80 by 40 mm and can typically process a 500-instruction program in less than 2 ms. It is available now; its suggested list prices begin at $249.

Allen-Bradley is supporting the new PLCs with three accessory products: a hand-held programmer (HHP) and two operator interfaces. The programmer is useful for making run-time adjustments as well as programming and editing. It has a carbon-rubber keypad and a two-line, 16-character liquid-crystal display. It also lists for $249 and will be available in March.

The simpler of the operator interfaces, called the MicroView, provides an operator with data-display, data-entry, and recipe download capabilities. In addition to a two-line LCD like the one on the HHP, the MicroView has a numeric keypad and two user-programmable function keys. It will list for approximately $250 when it becomes available next month.

The second interface, the DTAM, provides all of the features and functions of the MicroView, but has eight function keys plus alarm functions. The DTAM is available immediately and lists for $625.

To make it easy for users of Allen-Bradley's SLC 500 small programmable controllers to switch to the new family, the MicroLogix 1000 uses the same programming package as the earlier product. *Contact: Allen-Bradley Response Center, Department AG/4128, Box 3064, Cedar Rapids, IA 52406-3064; 612-946-7300 (ask for Allen-Bradley); toll-free, 800-223-5354, ext. 4128; toll-free fax, 800-545-1179; or* **circle 102.**

computers

Super vision for less

The cost of the Silicon Graphics Inc. hardware used to dazzling effect in the movies *The Flintstones*, *Forrest Gump*, and *The Mask* [*IEEE Spectrum*, October 1994, p. 19] runs to six figures at a minimum. That kind of expense has forced even Ford Motor and General Dynamics to ask their engineers to share the machines, whose visualization power is valued for designing cars and submarines. Others have been simply priced out of the market.

So here's a toast to the arrival next month of the Reality Station. For \$94 900, or 40 percent less than previous computers in the powerful Onyx family, the new workstation still rewards buyers with the source of the Onyx visualization capability—the Reality Engine^2 graphics subsystem.

▲ The Reality Station workstation (left) provides lower-priced access to the high-performance graphics capability of Silicon Graphics' Onyx computer line.

The new system's central processor is a single 200-MHz MIPS 4400 chip (earlier Onyx systems employed at least two processors). Even so, the Reality Engine^2 subsystem provides full graphics capability: 1.5 million triangles per second, real-time multisample antialiasing, a minimum of 4MB of texture memory, three-dimensional volumetric textures, 48-bit quad-buffered color, and scalable pixel fill and resolution.

The system comes equipped with a VGA monitor (it also supports HDTV format), the IRIX 5 operating system, and a minimum of 2GB of mass storage. *Contact: Silicon Graphics Inc., 2011 North Shoreline Blvd., Mountain View, CA 94043; 415-960-1980; toll-free, 800-800-7441; in Europe, (41+22) 798 7525; on the World Wide Web, the universal resource locator (URL) is http://www.sgi.com/; or* **circle 103.**

software

Imaging tool extracts forms

Imagine 4.0, the latest version of the custom control imaging package from Imagination Software Inc., adds forms recognition and extraction along with programmable annotations, mark sensing, intelligent character recognition, and color to the capabilities of earlier versions. A Visual Basic application for scanning, viewing, printing, storing, and manipulating images, Imagine is a highly flexible product that is easily customized to individual needs.

Its clean-up feature can de-skew, despeckle, and de-shade captured images as well as remove lines and other extraneous objects. Its overlay forms feature helps users such as government agencies save storage space by using one copy of a form with many images of data records.

Its new forms features identify forms from images and optionally extract the filled-in information into another image file. The features include provisions for managing forms libraries.

Imagine runs under Windows 3.1 and is compatible with Visual Basic, Visual C++, and Borland C+. It supports over 40 image formats, including JPEG, GIF, TIFF, EMS, BMP, PCX, CALS, and IMG. It can in addition read 12 bar codes, among them: Code 39, Code 128, Codabar, 3 of 5, and 3 of 5 (interleaved).

Imagine 4.0 is priced at \$695 for a single-user license. *Contact: Imagination Software Inc., 8737 Colesville Rd., Suite 301, Silver Spring, MD 20910; 301-588-8411; fax, 301-588-1912; or* **circle 104.**

new & noteworthy

- Powerex Inc., Youngwood, Pa., has expanded its line of **insulated-gate bipolar transistors (IGBTs)** to include 1000-A versions rated at 1200 and 1400 V. The 1200-V unit is priced at \$1050 in lots of 10 pieces. **Circle 105.**
- Design Science Inc., Long Beach, Calif., has announced version 3.1 of its popular MathType software **for creating and editing mathematical equations** on both Macintosh and Microsoft Windows computers. The new version adds native Power Macintosh support, new commands for Microsoft Word 6.0, and support for EGO (edit graphic object). Equations developed with MathType may be inserted into almost any Macintosh or Windows word processor, desktop publishing setup, or graphics application. The package lists for \$199. Upgrades are \$29.95 to registered users of version 3.0, \$49.95 for versions 2.x and 1.x, and free to users who bought version 3.0 after Oct. 1, 1994. **Circle 106.**
- By adding quick-disconnect terminals to several of its **3U-size termination panels,** Intelligent Instrumentation Inc., Tucson, Ariz., has not only shortened initial wiring and assembly but also speeded up and simplified the post-installation tasks of removing and reconfiguring the panels. The quick-disconnect terminals are being offered on the company's optically isolated panels, digital relay output panels, and digital isolated input panels, which have list prices of \$130, \$205, and \$235, respectively. **Circle 107.**
- The DAQP-12 from Quatech Inc., Akron, Ohio, is **a data-acquisition system built into a Type II PCMCIA adapter** with eight differential or 16 single-ended analog input channels. There are two versions—one with programmable gains of 1, 2, 4, and 8, and the other with gains of 1, 10, 100, and 500. Both can sample signals at 100 kilosamples per second at 12-bit resolution. The DAQP-12 is priced at \$695. **Circle 108.**
- NCL America Computer Products Inc., Sunnyvale, Calif., has announced a family of **low-cost RAID (redundant array of inexpensive disks) controllers** to protect data stored in file servers in Novell networks and on desktop computers operating in OS/2, DOS, and Windows environments. The new controllers boost system throughput by incorporating split seeks and concurrent write operations. They support two IDE hard drives simultaneously, as well as two 130-mm or two 90-mm floppy-disk drives. Members of the 8000 family are priced from \$269 to \$349. **Circle 109.**
- **A calibration service for photovoltaic modules** is being offered by Spire Corp., Bedford, Mass. The company will perform current-voltage measurements using one of its Spi-Sun 240A simulators and a reference cell calibrated against a primary standard from the U.S. Department of Energy's Renewable Energy Laboratory. The Spi-Sun 240A has a Class A spectral match and a uniformity of ±3 percent across its 800-by-1300-mm test area. **Circle 110.**
- Volume 1 of the *PC Systems Handbook* from CyberResearch Inc., Branford, Conn., which is **a combination buyer's guide, how-to handbook, and catalog of data-acquisition products**, is now being offered free of charge to qualified technical professionals. Volume 2 will follow shortly. **Circle 111.**

MICHAEL J. RIEZENMAN, Editor
RICHARD W. COMERFORD, Contributor
PAUL A.T. WOLFGANG, BOEING DEFENSE & SPACE GROUP, Consultant

EMPLOYMENT OPPORTUNITIES

Organizations seeking engineers and scientists describe their various openings in the following advertising section

In order to conform to the Age Discrimination in Employment Act and to discourage age discrimination, IEEE may reject any advertisement containing any of these phrases or similar ones, "recent college grads," "1–4 years maximum experience," "up to 5 years experience," or "10 years maximum experience." IEEE reserves the right to append to any advertisement, without specific notice to the advertiser, "Experience ranges are suggested minimum requirements, not maximums." IEEE assumes that, since advertisers have been notified of this policy in advance, they agree that any experience requirements, whether stated as ranges or otherwise, will be construed by the reader as minimum requirements only. While IEEE does not ban the use of the term "entry level," its use is discouraged since, to some, it connotes an age rather than an experience designation. IEEE accepts employment advertising to apprise its members of opportunities. Interested parties should be aware that the political and humanistic values of certain advertisers may differ from their own. IEEE encourages employers to offer salaries that are competitive, but occasionally a salary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

To place an advertisement in *Spectrum's* Employment Opportunities section, contact the nearest *Spectrum* sales office

212-705-7760	508-255-4014	708-446-1444	415-386-5202	310-649-3800	404-256-3800	214-553-9896	303-670-3749
New York	Boston	Chicago	San Francisco	Los Angeles	Atlanta	Dallas	Denver

For production/mechanical information contact Martin Barbieri Advertising Production Manager, 908-562-6334

IEEE Spectrum Advertising Dept., 345 E. 47th St., New York, N.Y. 10017

On-line Technical Support Engineers

Hewlett-Packard's Englewood, Colorado Sales office has immediate openings for highly creative and motivated individuals to provide on-line technical support peaked in test and measurement and software to help establish the call center of the future.

You will provide telephone technical support for customers relating to HP's computer and test equipment in the fields of RF Microwave, Computer-Aided Test, Logic Analyzers/Scopes, and Low Frequency Physical Measurements. You will also assist field personnel in pre-sales activities by providing real-time customer feedback. Requires a BSEE (MSEE preferred) or a BSCS plus a minimum of 2-3 years of experience working in or with test and measurement related products/industries. Previous experience in call management techniques, networking (LAN Manager/X, TCP/IP, PPP, SLIP, Arpa/Berkely), and HP-UX and MS Windows* management skills are necessary. Demonstrated teamwork and customer satisfaction skills, good phone attitude with capability of identifying problems and providing resolution as well as the willingness to learn a must.

We offer a competitive compensation package. To apply for the Englewood opening, please forward your resume with salary requirements to: **Hewlett-Packard Employment Response Center, Attn: Ad #1093, 3000 Hanover Street, MS 20AZ, Palo Alto, CA 94304-1181.** Hewlett-Packard Company is an equal opportunity employer dedicated to affirmative action and work force diversity.

*MS Windows is a U.S. trademark of Microsoft Corporation.

HEWLETT® PACKARD

The Technische Universität Wien, Vienna, Austria, Department of Electrical Engineering, invites applications for the newly endowed position of a full professor of Communication Networks.

The holder of the chair will be responsible for both teaching (in English or German) and research. The successful applicant shall have extensive experience in one or more of the following fields:

- network architecture and design,
- intelligent networks and services,
- communication protocols and signalling,
- modelling and simulation of communication networks,
- switching.

The candidate is expected to address applications as well and to take into account social implications of communication technology. Outstanding scientific qualifications, teaching abilities, and industrial or industry-related research activities are essential.

A Ph.D. in electrical engineering or in related areas is a formal requirement. (A working knowledge of German will be appreciated.)

The Technische Universität Wien is an equal opportunity employer and strongly invites women to apply.

Send applications including curriculum vitae, list of publications, reprints of five significant articles, list of courses held (if applicable), and summary of current research activities to:

Prof. Dr. Alexander Weinmann, Dean, Department of EE, T.U. Wien, Gusshausstrasse 27-29/350, A-1040 Wien, Austria, not later than **March 15, 1995.** (FAX: +43-1-505-89-07, e-mail: weinmann@iert.tuwien.ac.at).

IEEE Presents Its 1995 Plans for Conference Proceedings

THE 1995 IEEE PREPAID ORDER PLAN (POP)

Subscribe to the 1995 POP plan and you'll get about 130 major 1995 IEEE conference proceedings — for $11,995! This is the standard plan libraries have received for decades.

THE 1995 IEEE PREPAID ORDER PLAN PLUS (POP PLUS)

The 130 major conferences discussed above plus about 80 new 1995 IEEE conferences, workshops, and symposia in rapidly-emerging technologies — for $16,975! POP Plus is all the 1995 IEEE conferences, in electrical engineering and computing in one plan.

SUBSCRIBERS TO BOTH PLANS RECEIVE:

- about a 38% savings off the total list prices of individual conferences
- a quarterly listing of the proceedings they should have received

IEEE
THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

To order or for more information, contact:
Robert S. Hohwald
(phone) **1-908-562-3999**
(fax) **1-908-981-8062**
(e-mail) INTERNET:r.hohwald@ieee.org

ISSA/NSA POLY

USE YOUR "TICKETS" FOR FASTER CAREER GROWTH

Put our 27+ years experience placing technical professionals to work for you. All fees paid. Nationwide opportunities in Communications, Defense, Intelligence, Computer, Satellites and Analytical Sciences. If you earn over $35,000, we have a better, more rewarding job for you ... right now. U.S. citizenship and ISSA/NSA POLY desirable. Call (301) 231-9000 or send your resume in confidence to: Dept. EA-I3EB or FAX to: (301) 770-9015.

WALLACH associates, inc.
Technical and Executive Search
Washington Science Center
6101 Executive Boulevard
Box 6016
Rockville, Maryland 20849-6016

calendar

Continued from p.14E6

Rasberry Patch Drive, Rochester, NY 14612–2868; 716-392-3862; fax, 716-392-4397.

Conference on Insulating Films on Semiconductors (ED); June 7–10; Grand Hotel de Paris, Villard-de-Lans, Grenoble; Sorin Cristoloveanu, LPCS, Enserg, BP 257, 23, Rue des Martyrs, 38016 Grenoble, Cedex 1, France; (33+76) 85 60 40; fax, (33+76) 85 60 70.

First International Conference on Multiagent Systems—Icmas '95 (C); June 12–14; San Francisco Hilton and Towers; Victor Lesser, Computer and Information Science Department, University of Massachusetts, Amherst, MA 01003; 413-545-1322; e-mail, lesser@cs.umass.edu.

Workshop on Higher-Order Statistics (SP); June 12–14; Parador de Aiguablava, Girona, Spain; Javier R. Fonollosa, Department of Signal Theory and Communications, Universitat Politécnica de Catalunya, Apartado 30.002, 08071 Barcelona, Spain; (34+3) 401 7052; fax, (34+3) 401 6447; e-mail, fono@tsc.upc.es.

Power Electronics Specialist Conference—PESC '95 (PEL); June 12–15; Swissotel, Atlanta, Ga.; Hans B. Puttgen, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250; 404-894-2927; fax, 404-894-2997.

32nd Design Automation Conference (CAS); June 12–16; Moscone Center, San Francisco; MP Associates, Inc., 5305 Spine Rd., Suite A, Boulder, CO 80301; 303-530-4333; fax, 303-530-4334; e-mail, mpa@dac.com.

Pulp and Paper Industry Conference (IA, Vancouver); June 12–16; Westin Bayshore, Vancouver, BC, Canada; Philip Fransen, c/o Fransen Engineering Ltd., 210-3031 Viking Way, Richmond, BC V6V 1W1, Canada; 604-270-7728; fax, 604-270-6252.

International Conference on Communications (COM); June 18–21; Seattle Sheraton Hotel and Towers, Washington; Michael Lupton, U. S. West Communications, 1005 17th St., Denver, CO 80202; 303-896-7657; fax, 303-896-8481.

Stockholm Power Tech (PE); June 18-22; Royal Institute of Technology, Sweden; R. Eriksson, Department of Electric Power Engineering, Royal Institute of Technology, S-100 44 Stockholm, Sweden; (46+8) 790 7988; fax, (46+8) 205 268; e-mail, stockholm95@ekc.kth.se.

International Symposium and USNC/URSI Radio Science Meeting (AP); June 18–23; Newport Beach Marriott Hotel and Tennis Club, California; William Imbriale, Jet Propulsion Laboratory 144-201, 4800 Oak Grove Dr., Pasadena, CA 91109-8099; 818-354-5172; fax, 818-393-6743; e-mail, imbriale@voyager.jpl.nasa.gov.

Device Research Conference (ED); June 19–21; University of Virginia, Charlottesville; Umesh K. Mishra, ECE Department, University of California, Santa Barbara, CA 93106; 805-893-3586; fax, 805-893-2149.

innovations

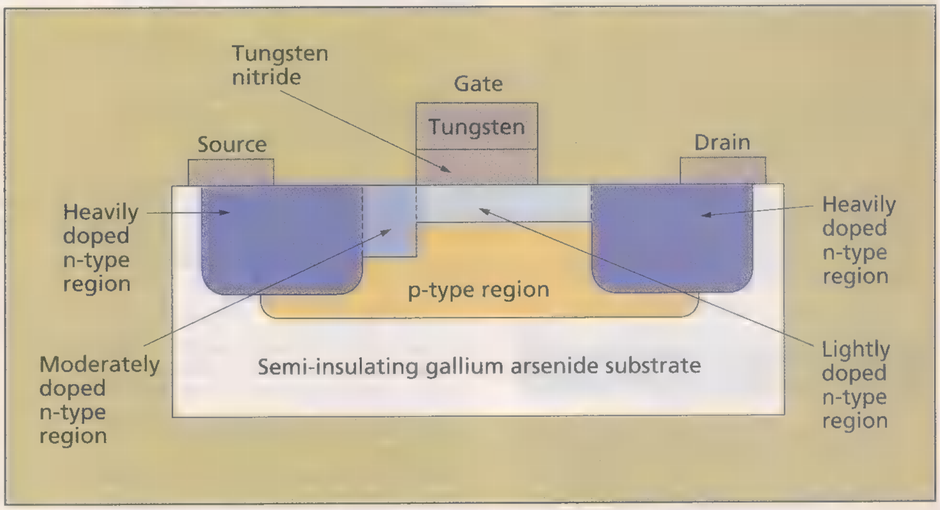
Gallium arsenide shrinks power pack

The world's tiniest power-amplifier module is on the way from Toshiba Corp., Tokyo. The November announcement said that the low-power device is intended for use in smaller low-cost transceivers for the 1.9-GHz Personal Handy Phone, a type of digital mobile communication system now under development in Japan.

The square module is 5.5 mm on a side and 2.0 mm high. So it is about a third the size of the power amplifier modules used for the systems now being tested. Better still, it operates at a single low voltage of 2.7 V—reportedly the first power metal semiconductor FET (MESFET) based on gallium arsenide to use a supply of less than 3 V. Last, its simplified IC design lends it to mass production.

The key to the MESFET is refractory gate technology, in which a magnetron is used to sputter compounds with high melting points onto parts of a device (here, the gate). The approach augurs well for power MESFET production because of the simplicity of the process, good device reliability, and stability over the long term, reported research scientist Masami Nagaoka and his 10 colleagues from Toshiba's Research and Development Center in Kawasaki, Japan.

The power MESFET has a planar but asymmetric structure, defined by the implantation of ions into a semi-insulating GaAs substrate [see illustration]. The FET is a self-aligned structure, meaning that its source and drain regions line up with the gate electrode of their own accord, without help from a resist process. The gate is 0.6 µm long and consists of a 300-nm-thick layer of tungsten deposited on a 120-nm-thick layer of tungsten nitride.



An n-type channel layer less than 50 nm thick is formed out of implanted silicon ions; beneath it, a thicker p-type layer of implanted magnesium ions eliminates the short-channel effects.

(An n-type layer is one doped to have an excess of negative carriers of electric charge, namely electrons; a p-type layer is one doped to have an excess of positive carriers, or holes.) The source-side region is self-aligned to the gate electrode, and the drain-side region is 0.3 µm off the gate.

Nagaoka and his colleagues report that at a gate voltage of 0 V, the MESFET's transconductance was as high as 280 millisiemens with a total gate width of 1 mm. "Such high transconductance realizes good rf output power performance even at a gate bias of 0 V," they wrote in the digest of the IEEE MTT-S International Microwave Symposium held May 23–27, 1994. "In addition to a sufficient breakdown voltage of less than –6 V, a very small drain knee voltage of 0.6 V was attained, which is essential for high-efficiency and low-voltage operation."

The power module was introduced at the Asia Pacific Microwave conference in Chiba, Japan. It is still under development, and no plans have yet been announced for its commercialization.

Simple full-color LEDs

A single organic material is the basis for miniature light-emitting diodes (LEDs) that generate red, green, and blue, the three primary optical colors, and that could readily be induced to emit purple or even white. Ordinarily, three chemicals must be integrated to achieve a full-color electroluminescent flat-panel display—a difficult and expensive manufacturing process.

To produce the LEDs, a team at AT&T Bell Laboratories in Murray Hill, N.J., played games with Alq (8-hydroxyquinoline), an organic compound patented by Eastman Kodak Co. Alq can emit only greenish light, but the wavelength can be changed by passing the light through carefully tailored microcavities.

Essentially, the team's members layered Alq over a terraced transparent surface and sandwiched the result between two mirrors, one terraced and one flat. Hence the microcavities.

The first step was to deposit a multilayered dielectric mirror on the rear surface of a glass screen. Next they overlaid the mirror with silicon nitride, an inert and transparent material, which they etched selectively to varying thicknesses. Then they overlaid the silicon nitride with films of Alq plus materials that facilitate electrical contact. Lastly, they deposited a layer of a metal such as aluminum, to act as both a second mirror and an electrode to stimulate the Alq to emit light. A wavelength of the desired color is formed when the two mirrors are separated by a multiple of half the desired wavelength.

"The thickness and composition of each LED's emissive layer remains the same. It's the easily patterned inert filler—the silicon nitride—that determines an LED's color," noted a member of Bell Labs' technical staff, Ananth Dodabalapur. He conceived the idea for the terraced structures, which he calls patterned planar microcavities.

Going beyond the primary colors of red, blue, and green, Dodabalapur and colleagues Lewis Rothberg and Timothy Miller have been able to produce LEDs with microcavities that can emit mixed colors such as white and purple. The white-light LEDs may make it possible to develop thin, low-voltage backlighting for portable displays.

Although the laboratory prototypes use Alq, the fabrication process does not limit the LEDs to any one organic material.

TRUDY E. BELL, *Editor*

CLASSIFIED EMPLOYMENT OPPORTUNITIES

The following listings of interest to IEEE members have been placed by educational, government, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum* Magazine, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

ADVERTISING RATES
Positions open—$40.00 per line, not agency-commissionable.
Positions wanted—$40.00 per line, a 50% discount for IEEE members who supply their membership numbers with advertising copy.

All classified advertising copy must be received by the 25th of the month, two months preceding the date of issue. No telephone orders accepted. For further information call 212-705-7578. IEEE encourages employers to offer salaries that are competitive, but occasionally a salary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

Academic Positions Open

University of Illinois at Chicago, Full Professor: The EECS Department has an opening for a tenured full professor position. The areas of particular interest are Communications and Signal Processing, and Computer Engineering. All candidates are expected to have an outstanding research record and commitment to quality teaching. UIC is a Research-I University, one of 70 top-ranked universities nationwide. The EECS Department has 50 faculty members and 500 graduate students. The department has more than four million dollars per year in research funding (sources include NSF, ONR, DARPA, AFOSR), a substantial computing environment including 150 workstations and over 25,000 square feet of research labs (much of the lab space is in a new Engineering Research Facility). For fullest consideration, send a resume and the names of at least three references by March 31, 1995 to Dr. Robert V. Kenyon, Search Committee Chair, Department of EECS (M/C 154), The University of Illinois at Chicago, 1120 Science and Engineering Offices, 851 South Morgan Street, Chicago, Illinois 60607-7053. The University of Illinois at Chicago is an Affirmative Action/Equal Opportunity Employer.

University of Illinois at Chicago: The Department of EECS invites applications for tenure-track positions at both the junior and senior levels. Applications for instructorships are also invited. A Ph.D. in electrical engineering, computer science, or equivalent is required by date of appointment (except for instructorships). Candidates should have outstanding research and teaching potential. UIC is one of four Research-I Universities in the state of Illinois. The EECS Department has 50 faculty members and about 500 graduate students in EE and CS. Send a resume and the names of at least three references by March 31, 1995 to Dr. Robert Kenyon, Search Committee Chair, Department of EECS (M/C 154), The University of Illinois at Chicago, 1120 Science & Engineering Offices, 851 South Morgan Street, Chicago, Illinois 60607-7053. The University of Illinois is an Affirmative Action/Equal Opportunity Employer.

Department Chair: The Electrical Engineering Department of North Dakota State University is seeking applications and nominations for the position of Department Chair, with an anticipated starting date of August 1, 1995. The Chair must hold an earned Doctorate in Electrical Engineering or a closely related field. Candidates must have teaching experience, good communication skills with ability to motivate and lead faculty and students, plus demonstrated scholarly activity. The Chair is expected to contribute to the university, community, and the profession. Experience in industry, funded research, administration, management, and a BSEE are preferred. The department is ABET accredited with 20 faculty, 5 staff, 450 undergraduates, 40 graduate students (MS and PhD). Major areas within the Department are Bioengineering, Computer Engineering Communications, Controls, Electronics, Electromagnetic Compatibility, Microwaves, Power, Power Electronics, and Signal Processing. NDSU is located in a pleasant metropolitan community of 140,000 with 2 other Universities and is the cultural, industrial, and retail center of the region. Applications including a resume with names of 3 references should be sent to: Dr. Don L. Stuehm, Chair of the Search Committee, Electrical Engineering Department, North Dakota, State University, Fargo, ND 58105. Applications will be reviewed starting April 1, 1995. NDSU is an equal opportunity institution.

Texas A&M University: The Electrical Engineering Department expects to have several openings for tenure track faculty at all ranks. Applicants must have a Ph.D. degree or the equivalent or completion of all requirements by date of hire. For senior positions, applicants should have a proven record of scholarly contributions, and for junior positions, demonstrated potential for quality research and teaching is necessary. The salary is competitive and commensurate with qualifications and experience. Applicants are sought in the areas of computer engineering, microelectronics, power electronics, signal processing, and medical electronics. Applicants should send a complete resume, including names and addresses of three references to Dr. A.D. Patton, Department Head, Electrical Engineering Department, Texas A&M University, College Station, TX 77843-3128. Texas A&M University is an equal opportunity/affirmative action employer and actively seeks the candidacy of women and minorities.

Graduate Fellowships: Fellowships are available for M.S. or Ph.D. study in Electrical Engineering at Ohio University. Fellowships provide a yearly stipend of up to $20,000 for Ph.D. students and $16,000 for M.S. students plus tuition waiver. Applicants must be U.S. citizens and possess a B.S.E.E. or M.S.E.E. from an engineering department that has a basic or advanced program which is ABET accredited. Minimum undergraduate GPA's are 3.3/4.0. For consideration, send a brief resume and cover letter before February 23, 1994 to: Dr. Jeffrey Giesey, Dept. of Electrical and Computer Engineering, 335 Stocker Center, Ohio University, Athens, OH 45701-2979.

Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Faculty of Electronic Engineering & Faculty of Computer Science invite applications for faculty positions at all levels. Applicants must have a Ph.D. from a recognized University with a strong commitment to teaching, research, and publications. The Institute offers nationally competitive salaries and generous fringe benefits. The applicants should submit a curriculum vitae with names of three references to the Rector, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi, District Swabi, N.W.F.P. Pakistan. Fax # (92) 5372-71865. The Institute is an equal opportunity employer which does not discriminate based on sex, race, religion or ethnicity.

National Institute of Astrophysics, Optics and Electronics, Puebla, Mexico: The department of Electrical Engineering is seeking for faculty positions in the areas of microwave circuits, VLSI and DSP. The candidates should have a Ph.D. related to these areas and a distinguished record in research and/or teaching. Applications, including curriculum vitae, list of publications and references, should be sent before May 15, 1995 to: Dr. Jose Silva Martinez, P.O. Box 51 and 216, Puebla, 72000, Mexico. Email: jsilva@tonali.inaoep.mx.

National Chiao-Tung University, Department of Communication Engineering (Taiwan, ROC) invites applications for faculty positions at the Assistant, Associate, or Full Professor level. Applications are accepted, in the areas including but not limited to high-speed networking (with communication software experience preferred), coding and information theory, Electromagnetic interference and compatibility, and sub-millimeterwave technologies. Candidates should have a demonstrated record of accomplishment in the above areas. Interested candidates are requested to send Letter of Application, Resume and names of 3 or more references to: Chair, Search Committee, Dept. of Communication Engineering, 1001 Ta-Shieh Road, Hsinchu, Taiwan, ROC. Review of Applications will commence in March, 1995 and continue until the positions are filled.

University of Pennsylvania, Department of Mechanical Engineering and Applied Mechanics invites applications for a tenure track position at the Assistant Professor level in the areas of design and controls. Applicants with research and teaching interests in manufacturing will be given special consideration. The Department maintains a small student-to-faculty ratio and emphasizes excellence in teaching and in research. Candidates must have a Ph.D. and must be committed to teaching at the undergraduate and graduate levels as well as to supervising M.S. and Ph.D. research. Candidates will be expected to develop an externally-funded research program. Address inquiries and applications (resume, reprints, list of at least three references) to Professor Vijay Kumar, Chair, Search Committee, Department of Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA 19104-6315. The University of Pennsylvania is an equal opportunity/affirmative action employer.

The Microwave Remote Sensing Laboratory (MIRSL) of the University of Massachusetts is seeking highly-qualified Ph.D. candidates interested in exciting research opportunities in environmental remote sensing. MIRSL specializes in developing microwave and millimeter-wave sensing instruments for ground-based and air-

borne experiments and in the analysis of data measured with these sensors. Research is currently underway to remotely sense ocean surface winds, currents, wave dynamics and sea ice; atmospheric water vapor, turbulence, cloud dynamics, and severe storms; and foliated and snow-covered terrain and soil moisture. We seek students who wish to be involved in all aspects of our research, including problem identification, instrumentation development, field experiments, and data analysis. Appropriate candidates will have earned bachelor's degree with distinction in Electrical Engineering or Physics. Research assistantship stipends begin at $14,500/year. A limited number of fellowships at $16,000/year are also available. For more information, please contact Dr. James Mead, Room 113B, Knowles Engineering Building, University of Massachusetts, Amherst, MA 01003; phone (413) 545-2463. The University of Massachusetts is an Equal Opportunity/Affirmative Action Employer and encourages women and minorities to apply.

University of Hartford, Department of Electrical and Computer Engineering: The Department of Electrical and Computer Engineering at the University of Hartford invites applications for an anticipated tenure track faculty position at the Assistant Professor level. The University of Hartford is a private comprehensive university of more than 3500 students located on ■ 300 acre residential campus in West Hartford, CT. It offers a wide range of undergraduate and graduate degree programs in Arts and Sciences, Business, Music, Art, Engineering, Engineering Technology, Education, Nursing, and the Health Professions. The College of Engineering offers ABET accredited undergraduate degrees in Electrical, Mechanical, and Civil Engineering, an interdisciplinary B.S.E., and degrees in Computer Engineering, Music-Acoustics, Biomedical Engineering, and Environmental Engineering. The college also offers an M.Eng. program. The College of Engineering is housed in United Technologies Hall with some laboratories in the adjacent Dana Hall. The Engineering Applications Center is part of the College and facilitates research/consulting contacts with local industries. The successful candidate will be expected to instruct ■ wide range of EE and Computer Engineering courses, primarily Digital Signal Processing, Electrical Machinery, and Communications. A Ph.D. in Electrical Engineering or closely related field is required. Professional registration and prior teaching experience is desired. Continuation of research is required for tenure and candidates with research specialties in D.S.P., Electrical Machinery, and Communications will be given preference. Screening will begin on March 1, 1995 and continue until the position is filled. A letter of application/nomination, C.V., and the names and addresses of 3 references should be sent to Professor Ladimer S. Nagurney, Search Committee Chair, Department of Electrical and Computer Engineering, University of Hartford, West Hartford, CT 06117. The University of Hartford is an equal opportunity/affirmative action employer and specifically invites and encourages applications from women, minorities, and persons with handicaps.

Post-Doctoral Research Fellow in Photonics: The Center for Photonics and Optoelectronic Materials (POEM) at Princeton University is seeking applications from qualified candidates for appointment as a Post-Doctoral Research Fellow to work on the design and growth of indium phosphide-based optoelectronic device structures by gas source molecular beam epitaxy. Prospective candidates should have a PhD in electrical engineering, materials science, physics or associated fields, and should have hands-on in-depth experience with MBE growth fabrication, and characterization of devices such as lasers, modulators, etc. The successful candidate will work on independent research projects, as well as lead and organize larger group activities involving graduate students at all levels of expertise. Appointments are for one year with the possibility of extension. Salary level depends on experience. Candidates should send their resume and three letters of reference to Prof. Stephen R. Forrest, ATC/POEM, E-Quad. J303, Dept. of Electrical Engineering, Princeton University, Princeton, NJ 08544. Princeton University is an Equal Opportunity Employer.

Florida International University invites nominations and applications for a tenure track faculty position in the area of High Speed Communications. The appointment is anticipated to be at the Assistant level, however, outstanding candidates at all levels will be considered. The Department of Electrical and Computer Engineering at F.I.U. offers B.S., M.S., and Ph.D. degrees. Qualifications: Earned doctorate with a strong commitment to funded research, teaching and publications in telecommunications. Substantial funded research must also be shown by senior level applicants, plus the ability to interface with a research team with interests which include Microwave Design, High Speed Packaging/Multi-Chip Modules, Compound Semiconductor Devices, Noise and High Temperature Superconductor Applications. Rank and salary are commensurate with qualifications and experience. Minorities and women are encouraged to apply. Applications and Dates: All applications post marked on or before March 9, 1995 will receive full consideration. The positions will be available starting August, 1995. U.S. citizens or lawfully authorized aliens should send a letter addressing the qualifications above, ■ resume, and three references (names) to: Dr. Tadeusz Babij, Chair, Search and Screen Committee, Department of Electrical and Computer Engineering, Florida International University, Miami, Florida 33199. Florida International University is a state university located in Miami with over 26,000 students, of whom 1,800 upper division and graduate students are enrolled in the College of Engineering and Design. The School of Engineering has four departments: Electrical and Computer, Civil, Mechanical, and Industrial Engineering. FIU is an Equal Opportunity/Equal Access Employer and Institution.

The University of Kansas Department of Electrical Engineering and Computer Science invites applications for a tenure-track faculty position in the remote sensing area to begin in August 1995. Applicants at the rank of assistant professor and associate professor will be considered and must have a Ph.D. in electrical engineering or physics. The successful candidate is expected to teach and supervise students both at the undergraduate and graduate levels and conduct research in remote sensing or RF/microwave engineering. Applicants with a Ph.D. in physics must have research experience in microwave remote sensing or RF/microwave engineering. Assistant professor candidates should have a high potential for both teaching and research. Applicants for the rank of associate professor should have a distinguished research record and a strong interest in educational programs. Applications, including resume, description of teaching and research interests, and the names and addresses of at least three references, should be sent to Professor Prasad Gogineni at EECS Department, 1013 Learned Hall, University of Kansas, Lawrence, Kansas 66045. Applications received until the position is filled will be considered. The University of Kansas is an EO/AA employer.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

University of Northern Iowa - Tenure Track Position - Electro-Mechanical Systems Technology: Responsibilities: Teaching undergraduate/graduate courses in Electro-Mechanical area, including: DC & AC theory, solid-state electronics, PLC and process controllers, electronic circuit & board development, power systems analysis, thermodynamics, and fluid mechanics. Departmental needs may require other course assignments such as senior projects, general education, or other courses as determined by the department head. The position further includes responsibilities for curriculum development, laboratory development, undergraduate and graduate advisement, research, and departmental, college, and university level committees as assigned. Qualifications: An earned doctorate in a suitable technological field is required. Applicants must hold a degree in industrial technology or a directly related field with technical emphasis in electro-mechanical systems including electrical engineering, mechanical engineering, or thermal sciences. Other desirable qualifications include evidence of teaching excellence, excellent communication skills, industrial experience through technical and/or managerial positions or through consulting, and experience in funded research. Salary: Salary is competitive. The university offers excellent fringe benefits including TIAA-CREF retirement plans. Application Submission: Review of applications will begin on February 1, 1995 and continue until an appointment is made. The department encourages applications from minority persons, women, disabled persons and Vietnam era veterans. Please send letter of application, resume, official undergraduate and graduate transcripts, and three letters of recommendation to: Dr. Lou A. T. Honary, Chair, Electro-Mechanical Systems Search Committee, Department of Industrial Technology, University of Northern Iowa, Cedar Falls, Iowa 50614-0178. Phone: (319) 273-2563. UNI is an equal opportunity educator and employer with a comprehensive plan for affirmative action.

The University of Cincinnati, Department of Electrical & Computer Engineering and Computer Science: Applications are solicited for ■ tenure track faculty position in Electrical and Computer Engineering starting January, 1995. The prospective faculty member should have an earned Ph.D. in electrical engineering or applied physics. Applicants with expertise in high speed optoelectronic device fabrication and characterization are sought. The faculty member will be involved in research and teaching at both undergraduate and graduate levels. The individual will collaborate with established research programs in the area of nano/optoelectronics. Facilities in the department include a complete microfabrication facility, specialized equipment for plasma and reactive ion etching, focused ion beam implantation, chemical vapor deposition, molecular beam epitaxy, laser optical characterization, etc. The Department offers MS/Ph.D. programs in electrical engineering, computer engineering, and computing sciences as well as an ABET fully-accredited undergraduate program in Electrical and Computer Engineering. The Department has 45 full-time faculty, 240 full-time graduate students, 400 undergraduate students. Curriculum vitae and the names of three references should be sent to: Prof. Peter B. Kosel, Interim Head, Department of Electrical & Computer Engineering and Computer Science, P.O. Box 210030, University of Cincinnati, Cincinnati, Ohio 45221-0030. The University of Cincinnati is an Affirmative Action/Equal Opportunity employer and encourages and welcomes applications from women and minorities.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Division Chair and Associate/Professor of Electronics Engineering Technology: Supervises programs in Electronics Engineering Technology, Computer Engineering Technology, Computer Information Systems and Automotive Parts and Service Management. Administrative responsibilities as assigned by the Dean. Qualifications include masters degree (doctorate preferred) in engineering technology or related area. Six years teaching, three years industrial experience and demonstrated administrative skills are required. Qualified to teach multiple subjects in a TAC/ABET EET curriculum. Open until filled; screening starts March 13, 1995. Send letter of application, vitae, names, titles, addresses, and telephone numbers of three professional references to: Dr. John Tappen, Chair, ASET Search Committee, University of Southern Colorado, 2200 Bonforte Blvd., Pueblo, CO 81001. The University of Southern Colorado is an EO/AA employer.

Electronics Engineering Technology: Full-time, tenure-track faculty position at the assistant professor level starting Fall 1995 to teach in several of the following areas: circuits, analog and digital electronics, microprocessors, computer architecture, communications, and control systems. Specialties in digital electronics and computer architecture or communications control systems are desirable. Other duties include laboratory and curriculum development, supervising student projects, and advising. Masters degree in engineering, engineering technology, or ■ related area required, doctorate preferred. Three years of relevant industrial experience required. Send application, unofficial transcripts, resume, and names of three professional references to: Dr. John Tappen, Chair, Search Committee, University of Southern Colorado, 2200 Bonforte Boulevard, Pueblo, CO 81001-4901. USC is an AA/EO employer.

The Hong Kong Polytechnic University (formerly Hong Kong Polytechnic) invites applications for the following post: Department of Electronic Engineering: Principal Lecturer/Senior Lecturer in Computer Systems Software and Communication Engineering. The appointee will be required to teach and conduct research up to postgraduate level in one or more of the following areas: Distributed Processing and Systems, Operating Systems and Concurrent Programming, Software Engineering, Data Structure and Database Management Systems, Functional and Object-oriented Design, High Performance Computer Architecture/Intelligent Systems, Neural Networks and Fuzzy Theory/Modern DSP Applications, Speech/Digital TV and HDTV, Mobile Communication and RF design, High Speed Networks, Fibre Optics, Telecom Software and Networking, Electronic Circuits and Design. Applicants should have (a) a higher degree, preferably a PhD degree; (b) extensive experience in areas such as teaching, research, curriculum development, industrial/commercial/public service sector; and (c) academic leadership in a subject area. Salary and Conditions of Service: Principal Lecturer: HK$610,620 - HK$787,740 per annum, Senior Lecturer: HK$514,320 - HK$683,760 per annum. (US$1 = HK$7.73 as at 6 December 1994). Initial appointments are normally made on a fixed term gratuity-bearing contract of two years at the end of which, re-engagement is subject to mutual agreement. Other benefits include leave, subsidized housing, medical and dental schemes, and children's education allowance. Application: Application including curriculum vitae and names of three referees should be sent to the Personnel Office, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong before March 1, 1995. Fax (852) 2764 3374, E-mail: GSSTAFF@HKPCC.HKP.HK.

Carnegie Mellon University: The Department of Electrical and Computer Engineering at Carnegie Mellon University invites applications for a tenure track position. We are seeking highly qualified candidates who are committed to ■ career in research and teaching. We are interested in candidates with a strong background in analog and digital integrated circuit and system design. Candidates should feel comfortable teaching both analog and digital IC design courses. Industrial design experience is also desirable. The successful candidate will have the opportunity to form collaborations with one or more active research groups both within and outside the department. The department has active research programs in analog IC design, low power circuit design, and digital systems synthesis and verification. In addition, Carnegie Mellon has several research centers that offer the opportunity for collaboration. These include the Engineering Design Research Center (an NSF-ERC), the Data Storage Systems Center (an NSF-ERC), the Robotics Institute, and the SRC-CAD Center. Applicants should have ■ Ph.D. in electrical engineering or a related field. Carnegie Mellon University is an affirmative action equal opportunity employer. Applicants should submit a resume, a one page statement of research accomplishments and future plans, and three of their most significant conference or journal publications to: Professor Robert M. White, Head, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

University of South Carolina: The Department of Electrical and Computer Engineering is seeking applicants for a senior-level position at the rank of full professor to direct the Center for Machine Intelligence. The candidate must have an earned Ph.D. in Electrical Engineering, Computer Engineering, or a closely related field and have experience in the area of information technology including enterprise integration, database technology, workflow for business processes, machine intelligence, machine learning, and distributed artificial intelligence. The candidate will be expected to establish new research initiatives and secure funding for them. Prior teaching experience and an established record of obtaining and managing large grants is desirable. Submit resume and list of references to Dr. Robert O. Pettus, Chair, Department of Electrical and Computer Engineering, University of South Carolina, Columbia, SC 29208. The deadline for application is March 15, 1995. The University of South Carolina provides equal opportunity and affirmative action in education and employment for all qualified persons regardless of race, color, religion, sex, national origin, age, disability, or veteran status.

Purdue University School of Electrical Engineering invites applications for tenure-track faculty positions at all ranks. Primary need is for faculty with specialization in the areas of optics, circuit design, and computer operating systems; but all specialties will be considered. Responsibilities will include both teaching and research. Salary is commensurate with qualifications and experience. Applicants must possess a doctorate degree. Send a resume, including a statement of teaching and research interests and a list of three (3) references, to: Head, School of Electrical Engineering (Spec), Purdue University, West Lafayette, IN 47907. Purdue University is an Equal Opportunity/Affirmative Action employer.

Harvey Mudd College invites applications for an Assistant Professor of Bio- or Biomedical Engineering effective July 1, 1995. Candidates should combine ■ dedication to teaching with a superior research capability. Preference will be given to Bio- or Biomedical Engineers with a background in the design of microprocessor based systems, electronic instrumentation, and/or associated signal processing. Industrial or clinical experience is desirable. Harvey Mudd, one of the six Claremont Colleges, is a small, selective college of engineering and science that offers a highly rated, unified BS in Engineering along with a professional Master of Engineering for some of our own graduates. The department has strong research and design programs, many jointly with major universities and corporations in southern California. The candidate will help develop a new concentration in Biomedical Engineering, teach at least one engineering core course, and supervise projects in the Engineering Clinic. All applications received before March 15 will be considered; others will be reviewed until a final appointment is made. Send resume, transcripts, and three references to B. Samuel Tanenbaum, Department of Engineering, Harvey Mudd College, Claremont, CA 91711 (Fax 909-621-8967), E-mail: Sam_Tanenbaum@HMC.edu Harvey Mudd is an equal opportunity employer and particularly encourages applications from women and members of minority groups under-represented in engineering.

University of California, Irvine: The Department of Electrical and Computer Engineering invites applications for a tenure-track faculty position at the level of Assistant Professor in the areas of analog, mixed-mode, and/or low power VLSI circuit design. Candidates should have a strong interest and background in circuit design with an emphasis on applications to one or more areas such as signal processing, communications, instrumentations, or bioelectronics. An earned Ph.D. prior to June 30, 1995 is required. The position involves graduate and undergraduate teaching and research supervision; ■ strong commitment to teaching, outstanding communication skills, and excellent research credentials are essential. Apply to Professor and Chair, Allen R. Stubberud, Department of Electrical & Computer Engineering, University of California, Irvine 92717-2625. Applications should include a letter of research interests, resume, and the names and addresses of three references. To receive full consideration, applications should be received before February 28, 1995. UCI is an Equal Opportunity/Affirmative Action Employer committed to excellence through diversity.

Faculty Position, Computer Engineering or Electrical Engineering: The School of Engineering at the City College of The City University of New York invites applications for ■ tenure-track position in the field of computer engineering at the Assistant, Associate, or Professor rank anticipated for Fall, 1995. The appointment will be in either the Computer Science or Electrical Engineering Dept, dependent on the successful candidate's qualifications and interests. The candidate is expected to teach graduate and undergraduate courses (day and/or evening). Ability to teach and conduct research in areas of overlapping interests to both departments is a plus. Applicant must possess a Ph.D. in Computer Engineering, Electrical Engineering or Computer Science and outstanding academic credentials with a strong commitment to research and teaching at both the undergraduate and graduate levels. The candidate must demonstrate competence in at least one of the following areas:

READER SERVICE (CIRCLE NUMBERS)

1 PRODUCT AND ADVERTISING INFORMATION

1	11	21	31	41	51	61	71	81	91	101	111	121	131	141	151	161	171	181	191	201	211	221	231
2	12	22	32	42	52	62	72	82	92	102	112	122	132	142	152	162	172	182	192	202	212	222	232
3	13	23	33	43	53	63	73	83	93	103	113	123	133	143	153	163	173	183	193	203	213	223	233
4	14	24	34	44	54	64	74	84	94	104	114	124	134	144	154	164	174	184	194	204	214	224	234
5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	215	225	235
6	16	26	36	46	56	66	76	86	96	106	116	126	136	146	156	166	176	186	196	206	216	226	236
7	17	27	37	47	57	67	77	87	97	107	117	127	137	147	157	167	177	187	197	207	217	227	237
[illegible]	18	28	38	48	58	68	78	[illegible]	98	108	118	128	138	148	158	168	178	188	198	208	218	228	238
[illegible]	19	29	39	49	59	69	79	89	99	109	119	129	139	149	159	169	179	189	199	209	219	229	239
10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240

Print or Type only

Name ______________________ Title ______________________

Company ______________________

Address ______________________

City ______________________ State __________ Zip __________

Country ______________________ Business Phone ______________________

Send me information on joining IEEE *(circle one)*: Regular membership **300** Student **301**

2 ADDITIONAL COMMENTS

____

____

I would like: ______________________

Void after May 1, 1995 *Void overseas after June 1, 1995* 2/95

EMPLOYMENT
RTUNITIES

ɔrication of III-V semiconduc-
InGaAs/InP) and amorphous
id mask design for integrated
nd salary for this position is
ı experience and qualifica-
ul candidate is expected to
e or graduate courses in optics
ıs as well as developing an
ch program. He/she will also
/ to participate in the existing
arch cooperative and the opti-
earch center. Interested appli-
d a complete curriculum vitae
s to Prof. Richard C. Powell,
iences Center, University of
zona 85721, Refer to position
ı will remain open until filled.
Arizona is an EEO/AA/ADA
and minority applicants are

doctorate is required. Respond to Ms. Carol Desmond, Department Manager, Dept. of EE B204 E-Quad, Princeton University, Princeton, NJ 08544. Princeton University is an Equal Opportunity/Affirmative Action Employer.

The Departments of Electrical Engineering and Physics of The Ohio State University invite applications for a senior faculty position in the electronic materials area to be jointly appointed in both departments. The successful candidate will hold the position of Center for Materials Research (CMR) Scholar and will be closely affiliated with the CMR. The candidate will take a leadership role in electronic materials research and education, and other interdisciplinary materials activities at The Ohio State University. The candidate should have a demonstrated ability to interact and provide leadership in national/international academic and scientific arenas. Applicants must have a Ph.D degree in Electrical Engineering, Physics, Materials Science or a related field, an outstanding record of research on electronic materials, and an interest in teaching at the undergraduate and graduate levels. Send resume and names and addresses of five references to: Professor Yuan F. Zheng, Chairman, Department of Electrical Engineering, The Ohio State University, 2015 Neil Avenue, Columbus, OH 43210-1272. The Ohio State University is an equal opportunity/affirmative action employer.

Call for Postdoctoral Positions: The research center of Istituti Ortopedici Rizzoli invites applications for post-doctoral or senior contracts. The main research topics in the laboratory are computer- and robot-assisted orthopedic surgery and lower limb biomechanics (especially knee). Candidates must have experience in one of the two fields, and mechanical expertise will be given priority. Salary is commensurate with qualifications and experience. Applications and nominations will be received until positions have been filled, but individuals are encouraged to apply immediately. Candidates should submit a curriculum vitae, statement of research interests,

ment Equity program, Laval University intends to hire women for half of its vacant positions. In accordance with Canadian immigration requirements, priority will be given to Canadian citizens and permanent residents of Canada.

Rutgers University: The Department of Electrical and Computer Engineering anticipates an opening and invites applicants for a tenure-track position at the Assistant Professor level in the areas of circuit design and digital/analog electronics. Ph.D. in EE, or equivalent, and clear potential for distinguished performance in teaching and research are required. The successful candidate's duties will include teaching at the undergraduate and graduate levels, laboratory development, and establishment of scholarly activities in the area of specialization. CAD development, IC testing tools, IC clean-room fabrication facilities and comprehensive computing facilities currently exist within the department. A resume and the names of four references should be sent to Prof. B. Lalevic, Chair, Electrical and Computer Engineering, Rutgers University, PO Box 909, Piscataway, NJ 08855-0909. Rutgers is an equal opportunity, affirmative action employer.

Experimental Optoelectronics Device Faculty Position: The Optical Science Center of the University of Arizona is seeking to fill an Assistant/Associate Professor tenure-track faculty position in the area of optoelectronic device fabrication, design, and testing. Applicants must have a Ph.D. and expertise in some of the following areas: Semiconductor lasers, including QW lasers, DFB, DBR, surface-emitting, high-power, circular-grating lasers; grating design for active and passive components on semiconductor and amorphous substrates; other optical components such as detectors, waveguides, combiners, etc.; integrated wavelengths multi/demultiplexers for WDM systems; and optoelectronic integrated circuits (OEIC) and photonic integrated circuits (PIC). Desired expertise in fabrication processes and steps; micro- and nano-fabrication instruments; nano-lithography, such as electron-beam and FIB

ssouri-Rolla seeks applica-
ure track assistant professor
ntrol group. The group is
the areas of smart struc-
ontrols, intelligent systems,
y control projects. The indi-
cted to advise graduate stu-
ergraduate and graduate
in sponsored research. A
ngineering is required. Appli-
ought for a part-time lecturer position. For lecturer position an MS is required and only applicants with a strong motivation toward teaching basic undergraduate courses will be considered. U.S. citizenship or permanent residency is essential at the time of employment. Please send resume and the names of three references to: E.K. Stanek, Interim Chairman, Department of Electrical Engineering, University of Missouri-Rolla, Rolla, MO 65401-0249. Application deadline is March 31, 1995. The University of Missouri is an Equal Opportunity/Affirmative Action employer.

Professor & Dean, College of Computing Sciences & Engineering: The University of North Florida invites applications/nominations for Professor and Dean of the College of Computing Sciences and Engineering. Basic qualifications include an earned doctorate in an engineering discipline, successful administrative experience, credentials showing a record of teaching and scholarly accomplishment suitable for appointment as Professor, a commitment to excellence in undergraduate education, a commitment to faculty and student diversity and dynamic and motivational leadership supporting institutional growth, and the development of College programs into the next century. Other desirable qualifications include successful fund raising, industrial experiences, a record of development of new programs, and ABET leadership experience. Send letter of application, current vita, statement of work eligibility and the names of 3 to 5 references to: Chair of the Search Committee for the CSE Dean, Office of the Provost, University of North Florida, Jacksonville, FL 32224. Phone (904)646-2560. Deadline for applications is March 10, 1995. UNF is an equal opportunity/equal access/affirmative action institution.

The Electrical Engineering Department invites applications for a two-year temporary non-tenure track assistant or associate professor position in the field of computer engineering beginning August 1995. Even though funds are currently available for only two years this posi-

CLASSIFIED E
OPPORT

Division Chair and As
Electronics Engineeri
vises programs in E
Technology, Computer I
Computer Information S
Parts and Service Man
responsibilities as assig
fications include mas
preferred) in engineerir
area. Six years teachin
experience and demo
skills are required. Qu
subjects in a TAC/ABE
until filled; screening
Send letter of applicati
addresses, and teleph
professional reference
Chair, ASET Search C
Southern Colorado,
Pueblo, CO 81001. The
Colorado is an EO/AA

Electronics Engineering
tenure-track faculty p
professor level startin
several of the followin
and digital electronics,
puter architecture, com
systems. Specialties ir
computer architecture
trol systems are desira
laboratory and curriculum development, supervising student projects, and advising. Masters degree in engineering, engineering technology, or a related area required, doctorate preferred. Three years of relevant industrial experience required. Send application, unofficial transcripts, resume, and names of three professional references to: Dr. John Tappen, Chair, Search Committee, University of Southern Colorado, 2200 Bonforte Boulevard, Pueblo, CO 81001-4901. USC is an AA/EO employer.

The Hong Kong Polytechnic University (formerly Hong Kong Polytechnic) invites applications for the following post: Department of Electronic Engineering: Principal Lecturer/Senior Lecturer in Computer Systems Software and Communication Engineering. The appointee will be required to teach and conduct research up to postgraduate level in one or more of the following areas: Distributed Processing and Systems, Operating Systems and Concurrent Programming, Software Engineering, Data Structure and Database Management Systems, Functional and Object-oriented Design, High Performance Computer Architecture/Intelligent Systems, Neural Networks and Fuzzy Theory/Modern DSP Applications, Speech/Digital TV and HDTV, Mobile Communication and RF design, High Speed Networks, Fibre Optics, Telecom Software and Networking, Electronic Circuits and Design. Applicants should have (a) ■ higher degree, preferably a PhD degree; (b) extensive experience in areas such as teaching, research, curriculum development, industrial/commercial/public service sector; and (c) academic leadership in a subject area. Salary and Conditions of Service: Principal Lecturer: HK$610,620 - HK$787,740 per annum, Senior Lecturer: HK$514,320 - HK$683,760 per annum. (US$1 = HK$7.73 as at 6 December 1994). Initial appointments are normally made on a fixed term gratuity-bearing contract of two years at the end of which, re-engagement is subject to mutual agreement. Other benefits include leave, subsidized housing, medical and dental schemes, and children's education allowance. Application: Appli-

of research accomplishments and future plans, and three of their most significant conference or journal publications to: Professor Robert M. White, Head, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

University of South Carolina: The Department of Electrical and Computer Engineering is seeking applicants for a senior-level position at the rank of full professor to direct the Center for Machine Intelligence. The candidate must have an earned Ph.D. in Electrical Engineering, Computer Engineering, or a closely related field and have experience in the area of information technology including enterprise integration, database technology, workflow for business processes, machine intelligence, machine learning, and distributed artificial intelligence. The candidate will be expected to establish new research initiatives and secure funding for them. Prior teaching experience and an established record of obtaining and managing large grants is desirable. Submit resume and list of references to Dr. Robert O. Pettus, Chair, Department of Electrical and Computer Engineering, University of South Carolina, Columbia, SC 29208. The deadline for application is March 15, 1995. The University of South Carolina provides equal opportunity and affirmative action in education and employment for all qualified persons regardless of race, color, religion, sex, national origin, age, disability, or veteran status.

Purdue University School of Electrical Engineering invites applications for tenure-track faculty positions at all ranks. Primary need is for faculty with specialization in the areas of optics, circuit design, and computer operating systems; but all specialties will be considered. Responsibilities will include both teaching and research. Salary is commensurate with qualifications and experience. Applicants must possess a doctorate degree. Send a resume, including a statement of teaching and research interests and a list of three (3) references, to: Head, School of Electrical Engineering (Spec), Purdue University, West Lafayette, IN 47907.

University of California, Irvine: The Department of Electrical and Computer Engineering invites applications for ■ tenure-track faculty position at the level of Assistant Professor in the areas of analog, mixed-mode, and/or low power VLSI circuit design. Candidates should have ■ strong interest and background in circuit design with an emphasis on applications to one or more areas such as signal processing, communications, instrumentations, or bioelectronics. An earned Ph.D. prior to June 30, 1995 is required. The position involves graduate and undergraduate teaching and research supervision; a strong commitment to teaching, outstanding communication skills, and excellent research credentials are essential. Apply to Professor and Chair, Allen R. Stubberud, Department of Electrical & Computer Engineering, University of California, Irvine 92717-2625. Applications should include a letter of research interests, resume, and the names and addresses of three references. To receive full consideration, applications should be received before February 28, 1995. UCI is an Equal Opportunity/Affirmative Action Employer committed to excellence through diversity.

Faculty Position, Computer Engineering or Electrical Engineering: The School of Engineering at the City College of The City University of New York invites applications for a tenure-track position in the field of computer engineering at the Assistant, Associate, or Professor rank anticipated for Fall, 1995. The appointment will be in either the Computer Science or Electrical Engineering Dept, dependent on the successful candidate's qualifications and interests. The candidate is expected to teach graduate and undergraduate courses (day and/or evening). Ability to teach and conduct research in areas of overlapping interests to both departments is a plus. Applicant must possess a Ph.D. in Computer Engineering, Electrical Engineering or Computer Science and outstanding academic credentials with a strong commitment to research and teaching at both the undergraduate and graduate levels. The candidate must demonstrate competence in at least one of the following areas:

Parallel Computing-Algorithms and Architectures, High Performance Computers/Computing; Performance Evaluation; Human/Machine Interfaces and IO; Data Base; Video/Speech Coding and Compression, Fault Tolerant Computing. An outstanding research reputation, with the ability to attract external research funding, is required for senior positions, or ■ demonstrated research potential, for junior positions. Salary range is $29,931-$74,980. Rank and salary will depend on qualification, training, and experience. Qualified applicants should send a curriculum vitae, names and addresses of at least three professional references, and samples of recent publications to: Charles B. Watkins, Dean, School of Engineering, c/o Office of Affirmative Action, Admin Bldg Rm 206, The City College of The City University of New York, Convent Ave. at 140th St., New York, NY 10031. Deadline for receiving applications is March 31, 1995. The City College has a strong institutional commitment to the principle of diversity. In that spirit, we are particularly interested in receiving applications from a broad spectrum of people, including women and underrepresented groups. Reasonable accommodations provided for individuals with disabilities upon request. An Equal Opportunity/Affirmative Action Employer.

Research Staff positions available in Department of Electrical Engineering at Princeton University to conduct research in electronic materials, computer engineering or information science and systems. Most staff devote time principally to research, with some opportunities for teaching and thesis supervision when appropriate. A doctorate is required. Respond to Ms. Carol Desmond, Department Manager, Dept. of EE B204 E-Quad, Princeton University, Princeton, NJ 08544. Princeton University is an Equal Opportunity/Affirmative Action Employer.

The Departments of Electrical Engineering and Physics of The Ohio State University invite applications for a senior faculty position in the electronic materials area to be jointly appointed in both departments. The successful candidate will hold the position of Center for Materials Research (CMR) Scholar and will be closely affiliated with the CMR. The candidate will take a leadership role in electronic materials research and education, and other interdisciplinary materials activities at The Ohio State University. The candidate should have a demonstrated ability to interact and provide leadership in national/international academic and scientific arenas. Applicants must have a Ph.D degree in Electrical Engineering, Physics, Materials Science or a related field, an outstanding record of research on electronic materials, and an interest in teaching at the undergraduate and graduate levels. Send resume and names and addresses of five references to: Professor Yuan F. Zheng, Chairman, Department of Electrical Engineering, The Ohio State University, 2015 Neil Avenue, Columbus, OH 43210-1272. The Ohio State University is an equal opportunity/affirmative action employer.

Call for Postdoctoral Positions: The research center of Istituti Ortopedici Rizzoli invites applications for post-doctoral or senior contracts. The main research topics in the laboratory are computer- and robot-assisted orthopedic surgery and lower limb biomechanics (especially knee). Candidates must have experience in one of the two fields, and mechanical expertise will be given priority. Salary is commensurate with qualifications and experience. Applications and nominations will be received until positions have been filled, but individuals are encouraged to apply immediately. Candidates should submit a curriculum vitae, statement of research interests, reprints of significant publications to: Dr. Sandra Martelli, Ist. Ort. Rizzoli, Lab Biomeccanica, via di Barbiano 1/10, I-40136 Bologna, Italy. Fax +39-51-583789.

Georgia Institute of Technology: The School of Electrical and Computer Engineering currently seeks applicants for tenure track faculty positions at all levels. A Ph.D in EE, or equivalent, and clear potential for distinguished performance in teaching and research are required. Areas of special need include senior faculty in computer engineering and telecommunications. Resumes and statements of interest should be addressed to: Director, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250. Immigration status of non-US citizens should be indicated. Georgia Tech is an equal opportunity/affirmative action employer.

Laval University: The Department of Electrical Engineering invites applications for a tenure track position in the area of power systems. The successful applicant will teach and conduct research in power transmission networks, within a group involved with power systems, power electronics and industrial control. The applicant will work at both undergraduate and graduate levels. Requirements: hold a doctorate in engineering and be skilled in both writing and speaking French. Apply by March 1, 1995, to: Mr. Denis Angers, Head, Electrical Engineering Department, Pavillon Adrien-Pouliot, Laval University, Quebec City, Quebec, G1K 7P4, Canada. In accordance with its Employment Equity program, Laval University intends to hire women for half of its vacant positions. In accordance with Canadian immigration requirements, priority will be given to Canadian citizens and permanent residents of Canada.

Rutgers University: The Department of Electrical and Computer Engineering anticipates an opening and invites applicants for a tenure-track position at the Assistant Professor level in the areas of circuit design and digital/analog electronics. Ph.D. in EE, or equivalent, and clear potential for distinguished performance in teaching and research are required. The successful candidate's duties will include teaching at the undergraduate and graduate levels, laboratory development, and establishment of scholarly activities in the area of specialization. CAD development, IC testing tools, IC cleanroom fabrication facilities and comprehensive computing facilities currently exist within the department. A resume and the names of four references should be sent to Prof. B. Lalevic, Chair, Electrical and Computer Engineering, Rutgers University, PO Box 909, Piscataway, NJ 08855-0909. Rutgers is an equal opportunity, affirmative action employer.

Experimental Optoelectronics Device Faculty Position: The Optical Science Center of the University of Arizona is seeking to fill an Assistant/Associate Professor tenure-track faculty position in the area of optoelectronic device fabrication, design, and testing. Applicants must have a Ph.D. and expertise in some of the following areas: Semiconductor lasers, including QW lasers, DFB, DBR, surface-emitting, high-power, circular-grating lasers; grating design for active and passive components on semiconductor and amorphous substrates; other optical components such as detectors, waveguides, combiners, etc.; integrated wavelengths multi/demultiplexers for WDM systems; and optoelectronic integrated circuits (OEIC) and photonic integrated circuits (PIC). Desired expertise in fabrication processes and steps; micro- and nano-fabrication instruments; nanolithography, such as electron-beam and FIB

lithography, microfabrication of III-V semiconductors (GaAs/AlGaAs/InGaAs/InP) and amorphous (glass) materials; and mask design for integrated circuits. The level and salary for this position is commensurate with experience and qualifications. The successful candidate is expected to teach undergraduate or graduate courses in optics or related disciplines as well as developing an independent research program. He/she will also have the opportunity to participate in the existing optical circuitry research cooperative and the optical data storage research center. Interested applicants please forward ■ complete curriculum vitae and three references to Prof. Richard C. Powell, Director, Optical Sciences Center, University of Arizona, Tucson, Arizona 85721, Refer to position 95-100. The position will remain open until filled. The University of Arizona is an EEO/AA/ADA employer. Women and minority applicants are encouraged to apply.

The University of Missouri-Rolla seeks applications for a 1995 tenure track assistant professor position in the control group. The group is actively involved in the areas of smart structures, intelligent controls, intelligent systems, and interdisciplinary control projects. The individual will be expected to advise graduate students, teach undergraduate and graduate courses and obtain sponsored research. A Ph.D. in Electrical Engineering is required. Applications are also sought for a part-time lecturer position. For lecturer position an MS is required and only applicants with a strong motivation toward teaching basic undergraduate courses will be considered. U.S. citizenship or permanent residency is essential at the time of employment. Please send resume and the names of three references to: E.K. Stanek, Interim Chairman, Department of Electrical Engineering, University of Missouri-Rolla, Rolla, MO 65401-0249. Application deadline is March 31, 1995. The University of Missouri is an Equal Opportunity/Affirmative Action employer.

Professor & Dean, College of Computing Sciences & Engineering: The University of North Florida invites applications/nominations for Professor and Dean of the College of Computing Sciences and Engineering. Basic qualifications include an earned doctorate in an engineering discipline, successful administrative experience, credentials showing ■ record of teaching and scholarly accomplishment suitable for appointment as Professor, a commitment to excellence in undergraduate education, ■ commitment to faculty and student diversity and dynamic and motivational leadership supporting institutional growth, and the development of College programs into the next century. Other desirable qualifications include successful fund raising, industrial experiences, a record of development of new programs, and ABET leadership experience. Send letter of application, current vita, statement of work eligibility and the names of 3 to 5 references to: Chair of the Search Committee for the CSE Dean, Office of the Provost, University of North Florida, Jacksonville, FL 32224. Phone (904)646-2560. Deadline for applications is March 10, 1995. UNF is an equal opportunity/equal access/affirmative action institution.

The Electrical Engineering Department invites applications for a two-year temporary non-tenure track assistant or associate professor position in the field of computer engineering beginning August 1995. Even though funds are currently available for only two years this posi-

tion may be converted to tenure-track after two years. This position requires ■ Ph.D. in Electrical Engineering, Computer Engineering, or closely related area. Industrial experience with embedded controller applications is desired. Applicants should have a demonstrated ability in independent research and effective undergraduate and graduate teaching with excellent oral and written communication skills. The successful applicant will be responsible for helping to build a strong computer engineering program with an emphasis in embedded controller design and applications. The University of Nevada, located in Reno, NV, is a Land Grant University with 11 colleges including agriculture, engineering, mining, and medicine. The EE Dept. has three computer engineering laboratories, a cluster of HP workstations, and networked access to Sun, DEC, SGI, Convex, IBM, and Cray YMP machines. The Reno/Lake Tahoe area is in the Sierra Nevada with great skiing, hiking, and boating. Reno has a philharmonic orchestra, a city band, the Nevada Ballet, and varied cultural activities. San Francisco and Silicon Valley, where many of our graduates work, are nearby via air shuttle and car (4 hours). Send application letter, resume, and supporting material to Prof. D. Egbert, EE Dept. (MS 260), University of Nevada, Reno, NV 89557 (egbert@ee.unr.edu). Consideration of applicants will begin on March 1, 1995 and continue until the position is filled. AA/EOE the University of Nevada employs only U.S. citizens and aliens lawfully authorized to work in the United States.

Florida Atlantic University is seeking a faculty member on a tenure-track position at the Assistant Professor level. Priority teaching and research areas are electronics and digital signal processing. Experience in design using microprocessors is desired. Applicants must have a Ph.D. in Electrical Engineering or a closely related field, an excellent publication record and other evidence of research excellence. The faculty will be expected to initiate funded research projects and to teach undergraduate or graduate courses. Florida Atlantic University is located on Florida's Southeast coast in the heart of a growing high tech community and enjoys excellent relationships with local industry. Send resume to Chair, Faculty Search Committee, Department of Electrical Engineering, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431 by March 15, 1995. Florida Atlantic University, a member of the State University System of Florida, is an equal opportunity/affirmative action employer.

Clarkson University, Department Chair, Electrical and Computer Engineering: Department chair sought for the Electrical and Computing Engineering Department. The successful candidate will also occupy a named chair, carrying with it annual discretionary funds. Must have a Ph.D. in electrical or computer engineering, and ■ strong record of teaching undergraduates, publishing research, and obtaining external funding. Needs enthusiasm for leading and mentoring the faculty to achieve excellence in both teaching and research. The ECE Department currently has 15 faculty members, EAC-ABET accredited BS programs in electrical engineering and computer engineering, and a graduate program with M.E., M.S. and Ph.D. degrees. Specialized research laboratories include high voltage, motion control and robotics, and artificial intelligence facilities. The university's Center for Advanced Materials Processing has facilities available for research on electronic and optical materials and devices. Position will remain open until filled. Send resume, a statement of leadership philosophy, and the names of 5 professional references to: Dr. Goodaz Ahmadi, Clarkson University, PO Box 5725, Potsdam, NY 13699-5525. Clarkson University is an AA/EOE. POS #51-94.

The Catholic University of America: Electrical Engineering Department invites applications for ■ tenure-track faculty position at the Assistant Professor level. The position will be available for the Fall 1995 semester. The candidate must have a Ph.D. in either electrical or computer engineering with a strong background in computer hardware, networking, and analog and digital electronics. It is expected that the candidate would be involved in undergraduate and graduate teaching and research. The department offers B.E.E., M.E.E., M.S.E. and Ph.D. programs. Applicants please send: ■ resume, a statement of research and teaching interests, and a list of three references to Dr. Nader Namazi, Chairman of the Search Committee, Electrical Engineering Department, The Catholic University of America, Washington, DC 20064. The Catholic University of America is an Equal Opportunity/Affirmative Action Employer.

McGill University: The Department of Electrical Engineering invites applications for two tenure-track positions, at the Assistant Professor level, in Microelectronic Circuits and in Photonic Systems, beginning in September 1995. Candidates must have an earned Ph.D. degree, and a first degree in electrical or computer engineering is desirable. Important requirements are demonstrated excellence in research and a potential for excellence in teaching and leadership. The first position is designed to strengthen the Department's research program in microelectronic circuits, and its undergraduate teaching in circuits and electronics. Expertise in high-speed electronic circuits is preferred. The successful candidate for the position in Photonic Systems will be expected to participate in the research program associated with the BNR-NT/NSERC Industrial Research Chair in Photonic Systems, which is oriented to free-space optical systems. Limited term positions also exist in Control Systems and Software Engineering. Please send a resume and the names and coordinates of 3 references, and a one-page statement of research and teaching goals, before March 31, 1995, to Professor Nicholas C. Rumin, Chairman, Department of Electrical Engineering, McGill University, 3480 University St., Montreal, Quebec H3A 2A7, Canada; Fax 514-398-4470. Following Canadian immigration requirements, priority will be given to Canadian citizens and permanent residents of Canada. McGill University is committed to employment equity.

University of California, Riverside, Faculty Position in Electrical Engineering: University of California at Riverside, Marlan and Rosemary Bourns College of Engineering, invites applications for a tenure-track or tenured faculty position for the 1995-96 academic year. Applicants should have an earned Ph.D. in Electrical Engineering or a related field. Areas of particular interest include: (1) wireless digital communication, data, video and multimedia communication; (2) parallel and distributed architectures for signal and image processing and embedded processors and applications. Candidates for a junior position should demonstrate evidence of outstanding potential in research and teaching. Candidates for a senior position should have established an exceptional record of achievement in research and teaching. Salary level will be competitive and commensurate with appointment rank and qualifications. UC Riverside is a major research institution and a member of the nine-campus University of California System, widely regarded as one of the best systems of public higher education in the world. The growth plan for the college predicts ■ size of about 2000 undergraduate and 350 graduate students by the end of the decade. Riverside is one of the fastest growing counties in California, with affordable housing and easy access to beaches, mountains, cultural activities and attractions. Send application with resume, names and addresses of at least three references, and a statement of research and teaching objectives to: EE Search Committee Chair, College of Engineering, University of California, Riverside, CA 92521. Applications received by March 15, 1995 will receive full consideration. The University of California, Riverside is an Equal Opportunity, Affirmative Action Employer.

South Dakota School of Mines ■ Technology, Faculty Position - Computer Engineering: Tenure track faculty position available at the Assistant or Associate level in the Electrical and Computer Engineering Department, South Dakota School of Mines and Technology to begin August 15, 1995. Responsibilities will include both teaching and research. Applicants must possess a doctoral degree in Computer Engineering or in Electrical Engineering with a strong emphasis on Computer Engineering, and have completed all degree requirements by July 1, 1995. Salary is commensurate with qualifications and experience. South Dakota School of Mines and Technology, founded in 1885, has an enrollment of approximately 2,500 students and offers degrees in all the major branches of engineering and the physical sciences. The school is located in Rapid City, the second largest city in South Dakota, and the gateway to the Black Hills of western South Dakota. Applications, including a resume, a statement of teaching and research interest, and names and addresses of at least three references should be sent to: Computer Engineering Faculty Search Committee, Department of Electrical and Computer Engineering, South Dakota School of Mines and Technology, 501 East St. Joseph Street, Rapid City, SD 57701-3995. Phone (605)394-2451. Fax (605)394-2913. EMail ariemens@msmailgw.sdsmt.edu. Applications will be reviewed beginning March 1, 1995, and will be accepted until the position is filled. South Dakota School of Mines and Technology does not discriminate on the basis of race, color, national origin, sex, religion, age or disability in employment or the provision of service.

Postdoctoral/Research Faculty in Theoretical, Computational, and Experimental Chemistry and Physics: We are looking for exceptionally able (1) theoretical/computational chemists or physicists with a strong background in quantum or classical dynamics, intense light-matter interactions, quantum control of chemical dynamics, or related areas, (2) experimentalists, particularly with a background in one or more of the following: ultrafast lasers, atomic and molecular beams, laser generated x-rays, charged particle beams, or x-ray physics. Current research interests in our group include (1) theoretical and experimental quantum control of chemical dynamics with femtosecond lasers, (2) development of multi-terawatt femtosecond lasers and their application to high field chemistry and physics, (3) ultrafast, short wavelength electron and x-ray diffraction as applied to imaging molecular quantum dynamics. For a description of current group activities and personnel see our World Wide Web site, http://www-wilson.ucsd.edu/ or send email with no text to "wilsjob@ucsd.edu". To apply, please send a cv to Prof. Kent R. Wilson, Department

of Chemistry 0339, University of California, San Diego, La Jolla, CA 92093-0339. Affirmative Action/Equal Opportunity Employer.

University of Hawaii at Manoa, Department of Electrical Engineering, invites applicants for tenure-track associate professor or assistant professor positions with specialization in either of the following areas: (1) Communications, (2) Microwave engineering. Duties: Teach EE undergraduate and graduate courses, serve on university and department committees, conduct research and scholarly activities, and perform related tasks as assigned. Minimum Qualifications: Associate Professor: Ph.D. degree or completion of all requirements for a doctorate in electrical engineering; minimum of four years of full-time college or university teaching at the rank of assistant professor or equivalent, with evidence of increasing professional maturity; demonstrated scholarly achievement in comparison with peers active in the same field; demonstrated ability to plan and organize assigned activities, including the supervision of work of assistants when appropriate; ability to pursue and supervise research; strong commitment to both undergraduate and graduate teaching. Assistant Professor: Ph.D. degree or completion of all requirements for a doctorate in electrical engineering; demonstrated ability to teach; demonstrated scholarly achievement; ability to pursue and supervise research; strong commitment to both undergraduate and graduate teaching. Salary: negotiable dependent upon qualifications and experience. Send resume and three references by March 31, 1995 to: Professor Shu Lin, Chairman, Department of Electrical Engineering, University of Hawaii at Manoa, 2540 Dole Street, Holmes Hall 483, Honolulu, HI 96822. An Equal Opportunity/Affirmative Action Employer.

Chair, Department of Engineering Technology: Georgia Southern University invites applications and nominations for the position of Chair, Department of Engineering Technology, Allen E. Paulson College of Science and Technology. Applicants should have a minimum of a master's degree and a bachelor's degree in engineering technology or engineering; professional engineering registration; a strong record of teaching, scholarship, and service appropriate to senior rank and graduate faculty status; three years' industrial experience; knowledge of contemporary engineering practice; demonstrated leadership and interpersonal skills; commitment to collegiality and diversity; and involvement in professional organizations. Preferred qualifications include an earned doctorate and teaching experience in one of the four areas represented in the department. Position is available July 1, 1995. The Department has twelve faculty who offer separate TAC/ABET-accredited degree programs in civil, electrical, industrial, and mechanical engineering technology. Send a letter of application, C.V., unofficial transcripts of all undergraduate and graduate work and a list of three current references with titles, addresses, and telephone numbers to Dr. Fredrick J. Rich, Chair, Engineering Technology Chair Search Committee, Georgia Southern University, Landrum Box 8149, Statesboro, GA 30460. Postmark deadline is March 15, 1995. Information subject to Georgia Open Records Act. Individuals who need reasonable accommodations under the Americans with Disabilities Act should notify the search chair. Georgia Southern University is an equal opportunity/affirmative action institution. Search Number 30779.

Dartmouth College, Thayer School of Engineering, Faculty Position in Computer Engineering: Dartmouth College invites applications for a computer engineering faculty position at the level of Assistant or Associate Professor. Requirements include an earned doctorate in computer engineering, computer science, electrical engineering or related field. In addition, applicants should present evidence of excellence, or potential for excellence, in teaching and research. We are especially interested in applicants with interdisciplinary interests in the following fields: communications, signal processing, computational science, VLSI design, medical computing, and controls. Responsibilities include teaching at the undergraduate and graduate levels, conducting funded research and advising graduate students in the engineering and computer science Ph.D. programs. Dartmouth College is a small, highly selective university with graduate programs in the sciences, engineering, business administration and medicine. Dartmouth faculty currently have research interests that include parallel and scientific computing, signal and image processing, performance analysis, multimedia systems, and VLSI systems. The campus is located in a small New England town in an area known for its excellent outdoor and cultural activities. Applications with current resumes and the names of at least four references should be sent to: Computer Engineering Search Committee, Thayer School of Engineering, Dartmouth College, Hanover, NH 03755-8000, USA. Review of applications will begin February 1, 1995. Dartmouth College is an Equal Opportunity/Affirmative Action employer and encourages applications from women and members of minority groups.

Oregon State University: The Department of Electrical and Computer Engineering invites applications for a senior faculty position at Associate Professor or higher level in the general area of digital video processing and applications. This position is funded by Tektronix, Intel, US West, and the University. It offers a unique opportunity to develop and lead a new program in modern communications at Oregon State University in strong cooperation with industry. The Department is committed to establishing a leading program in emerging information technologies and their applications, including digital video processing, compression and communication, video networking, and personal communications systems. The successful candidate will assist the Department in recruiting additional faculty members for this program. Qualifications include an outstanding academic or industrial record, demonstrated excellence in teaching, significant involvement in research, and a doctorate or equivalent in electrical engineering, computer engineering, or computer science. The successful candidate must be committed to developing a strong digital communication program at OSU. With a faculty of 25, the Department of ECE enrolls about 425 undergraduate and 120 MS/PhD students. The department offers ABET accredited programs in electrical and computer engineering. High technology corporations such as Hewlett-Packard, Intel, Mentor, US West, and Tektronix have major operations in the area and provide support for the Electrical and Computer Engineering program. The Department has modern facilities housed in a new building. Located in the Willamette Valley 80 miles south of Portland, OSU and the city of Corvallis offer a beautiful and unspoiled environment and many cultural activities. Applications must include a comprehensive resume, a list of three to five professional references, and a letter of interest. The letter must indicate clearly the position for which you are applying. Please send material to Chairman, ECE Search Committee, Electrical and Computer Engineering Department, Oregon State University, Corvallis, OR 97331-3211. Review will begin April 1, 1995,

and continue until the position is filled. Oregon State University is an Affirmative Action/Equal Opportunity Employer and complies with Section 504 of the Rehabilitation Act of 1973. OSU has a policy of being responsive to the needs of dual career couples.

Industrial Research Chair in Real-Time Signal Processing: In anticipation of the establishment of an Industrial Research Chair in Real-Time Signal Processing, the Faculty of Engineering at the University of New Brunswick is inviting applications from highly qualified individuals. The industrial partner with the University is IOTEK, a dynamic and innovative firm with an established record in the development of real-time systems for military and commercial applications. The Chair will be in place in 1995. The appointment is a tenure track position in the Department of Electrical Engineering. Excellence of academic qualifications, industrial experience and willingness to collaborate with industry will be major factors in the Chair selection. The Electrical Engineering Department has research programs in place in the areas of real-time signal processing, adaptive algorithms for transient signal analysis, digital signal processing architectures and image recognition. In addition, cooperation will be expected with existing Industrial Research Chairs such as the Control & Instrumentation Chair. Candidates must have a PhD with a strong research record and demonstrated expertise in real-time signal processing. The emphasis of the Chair will be on the development of parameter estimation and tracking procedures, sensor data association and fusion, data base management and information visualization techniques for real-time systems. Experience in sonar signal acquisition and processing is highly desirable. Full collaboration with IOTEK and other industrial sponsors must be a commitment of the selected candidate. An important goal of the Chair will be the transfer of technology to industry. The University of New Brunswick is committed to the principle of employment equity. In accordance with Canadian Immigration requirements, priority will be given to Canadian citizens or permanent residents. Applications will be considered until the position is filled. Nominations, applications and requests for information should be forwarded to: Dr. Wolfgang Faig, Dean, Faculty of Engineering, University of New Brunswick, P.O. Box 4400, Fredericton, NB E3B 5A3. Fax: 506-453-4569.

Government/Industry Positions Open

Software Engineer: entry-level position to design, code, test & implement programs & enhancements for real-time security accounting mgmt systems. Emphasis on applications development in C and structured analysis & design for transaction processing systems. Write & modify program & operation documentation & reports. Assist in installation of software. Interface with customers & vendors including on-site visits. Requires: B.S. in computer science or related major (or foreign equiv.). Must have prior practical application of the following knowledge in a real-time environment: UNIX & VAX/VMS platforms, C, communications protocols, structured analysis & design. Must be eligible for NV gaming card. Job site: Reno, NV. 40 hr. work week. Salary: $34,500/yr. Successful applicant must prove legal right to work permanently in the U.S. Please submit resume and a copy of this ad to : #9428378, Nevada Employment Security Div., 70 W. Taylor St., Reno, NV 89509-1700.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Software Engineer for communications software development for complex real-time security accounting mgmt systems with an emphasis on applications development in C on UNIX, VAX/VMS and PC platforms, serial communications, networking, and structured analysis and design for transaction processing systems. Develop system and software specs, user documentation, program & operation documentation & reports. Requires: B.S. in computer science or related major (or foreign equiv.) and 1 yr. experience in job offered or 1 yr. in real-time software development. Must have prior practical application of the following knowledge in ■ real-time environment: structured analysis & design, serial communications, TCP/IP network communication protocols, and either UNIX IPC, CASE tools, or internals and device drivers. Must be eligible for NV gaming card. Job site: Reno, NV. 40 hr work week. Salary: $36,600/yr. Successful applicant must prove ability to work permanently in U.S. Please submit resume and a copy of this ad to : #9428356, Nevada Employment Security Div., 70 W. Taylor St., Reno, NV 89509-1700.

Database Administrator: Provide all RDBMS technical support: design, modifications, performance, capacity, integrity, security, reliability, upgrades, installations, and application integration. Evaluate, install ■ integrate third-party software & hardware. Responsible for LAN administration, PC support & backup VMS support. Requires frequent off-hour support, both on-site & remote on-line. Requires: M.S. Degree in Computer Science and 3 years experience in database administration, including 1 year experience or formal training in RDBMS technology and 2 years experience with data communications & PC LANs. Experience may be gained concurrently and must include work with ORACLE (full suite), SQR, PVCS, UDMS, XENTIS and MAXCIM. Resume/cover letter must reflect all requirements. Salary: 52,200.00; 40 hours/week in Redmond, WA. Send resume by March 8, 1995 to: Job Order #465094; Employment Security Dept., E & T Division; P.O. Box 9046; Olympia, WA 98507-9046.

Automated speech recognition co. seeks Speech Scientist to design & develop algorithms & software for speech recognition & related processing systems. Duties involve speech recognition technology & related disciplines, particularly DSP & pattern recognition. Will conceive, develop, implement, evaluate techniques to improve product lines. Will use computer programming skills to build & test solutions for design impediments. Will consult in areas of DSP, pattern recognition, and speech processing technologies. Must have Ph.D. in Electrical or Computer Engineering, + 2 yrs. experience in job offered or 2 yrs. in related engineering/research position. Must also have proven expertise in: (1) DSP techniques, e.g., filter design, parametric & speech time-frequency representations, and statistical modeling techniques, as applied to speech processing & voice recognition; (2) pattern matching systems, including statistical modeling, pattern recognition & neural networks; and (3) development of software & sophisticated algorithms, e.g., Hidden Markov models, multilayer perception theory & self-organizing networks, as applied to the representation & classification of speech signals. Salary: $60,000/yr. M-F, 40+ hrs./wk. Send 2 resumes to Job Order #50041, P.O. Box 8968, Boston, MA 02114. An EOE.

Software Support Engineer, by 3/3/95, please send resume to: Employment Security Department, E&T Division, Job # 471078-P, P.O. Box 9046, Olympia, WA 98507-9046. Job Order Number must be indicated on your response. Job Description: Provides technical support to independent software vendors and others developing applications to run on Windows operating system and related products. Answers service requests, designs and implements sample software modules and applications for internal and external use. Researches and documents errors in products, and writes technical articles concerning Windows programming. Utilizes "C" and "C++" programming languages and MS-DOS and Windows operating systems. Requirements: Bachelor's degree in Electrical Engineering, Computer Science, Mathematics or Physics or ■ related field; Six months experience in job offered; or six months work or school thesis project experience in programming or computer software design utilizing "C++" language and designing or implementing software to run on either (1) Windows operating system, or (2) MS-DOS and an event-driven windowing operating system. Experience must include six months work experience in providing technical support to computer users. Experience may be gained concurrently. 5 positions available. Must have legal authority to work in the United States. Job Location: Seattle Area Employer. Salary: $31,500-$41,500 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time. EOE.

Software Product Manager, by 3/3/95, please send resume to: Employment Security Department, E&T Division, Job # 470035-N, P.O. Box 9046, Olympia, WA 98507-9046. Job Order Number must be indicated on your response. Job Description: Develops technical requirements, manages product development, and works with program managers to write product specifications for network integration kit product to enable network operators to deploy interactive television software systems. Develops technical content of product training programs and marketing events, including sample software code and demonstration modules written in Visual Basic and "C++" to run on advanced windowing multitasking operating systems, to train internal account managers, independent software vendors, systems integrators, and key telecommunications network customers regarding network integration kit and end-to-end solutions for interactive television software systems. Conducts competitive technical analysis of interactive television software products, and writes technical papers for internal and external distribution discussing product features in detail. Requirements: Master's degree in Electrical Engineering or Computer Science; Two years experience in job offered; or two years work experience as a Programmer or Software Designer in design and implementation of groupware and multimedia software systems and/or applications, to include six months work experience or minimum of semester long or equivalent school thesis project or graduate school course project (minimum 3,000 lines of code) in programming or computer software design utilizing "C++" programming language, object oriented design techniques, and design and implementation of relational database management system software, and software to run on distributed, multitasking operating systems. Experience may be gained concurrently. Experience must include six months of technical account management in the software industry. Must have completed a thesis or published an article. Must have legal authority to work in the United States. Job Location: Seattle Area Employer. Salary: $46,000-$54,500 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time. EOE.

Corporate Network Support Engineer: By 3/3/95, please send resume to: Employment Security Department, E&T Division, Job # 467165-K, P.O. Box 9046, Olympia, WA 98507-9046. Job Order Number must be indicated on your response. Job Description: Provides technical support to and manages support relationships with corporate customers of networking operating systems products, including beta testing of networking operating systems before final product release. Answers questions from subscribers of Online product support services and designs and implements programs to resolve customer usage problems, including problems due to bugs in source code of product. Utilizes MS-DOS and multitasking (Unix and Windows NT) operating systems and "C" and 86 Series Assembler language. Requirements: Bachelor's degree in Computer Science; Two years experience in job offered; or two years of work experience as a technical support engineer, to include one year of experience in computer network administration, to include six months work experience or minimum of semester long or equivalent school thesis project experience in programming or computer software design using MS-DOS and Unix operating systems and "C" or 86 Series Assembler language. 20 course hours in computer networks or CNE (Certified NetWare Engineer) certification. Experience may be gained concurrently. Must have legal authority to work in the United States. Job Location: Seattle Area Employer. Salary: $40,500-$46,500 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time. EOE.

Software Program Manager, by 3/3/95, please send resume to: Employment Security Department, E&T Division, Job # 471170-B, P.O. Box 9046, Olympia, WA 98507-9046. Job Order Number must be indicated on your response. Job Description: Designs software for micro computers following standard procedures. Coordinates program development of components of online information service product, including administrative and system tools, graphical user interface of tools, and database components. Works with software developers, software testers, user education team, information services operations group, and third party suppliers to ensure product is developed on schedule and in conformity with specifications. Performs technical analysis of competing products and works with product managers to determine strategic technical marketing direction. Utilizes "C" programming language. Requirements: Bachelor's degree in Electrical Engineering, Computer Science, Mathematics or Physics; Six months experience in job offered or six months of work experience or minimum of semester long or equivalent school thesis project experience in programming or computer software design utilizing "C" language; design and implementation of graphical or full screen user interface software; and design and implementation of telecommunications software. 20 course hours in business/ marketing analysis or six months of work experience in business marketing. Experience may be gained concurrently. Must have legal authority to work in the United States. Job Location: Seattle Area Employer. Salary: $37,500-$52,000 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Circuit Design Engineer: Consumer electronics company is seeking an experienced individual to head ■ product development team. Candidate must have ■ strong analog and digital circuit design background. Must have PAL, GAL and Microcontroller programming experience. Analog RF circuit design experience required. Experience with NTSC video and CATV a plus. Individual must be able to work independently and be competent at all levels of product development. Send resume with two references to: Everquest Inc., Engineering Div., 875 South 72nd Street, Omaha, NE 68114.

Senior Software Engineer: Oversee APCO-25 compatible real-time software application development & maintenance for two way radio dispatch consoles involving link control services, embedded & supplementary data functions, ■ narrowband land-mobile data communications protocol, & block protocols for synchronous & asynchronous computer communications. Develop & test these applications utilizing the Hatley & Pirbhai Structured System Specification & Design method, HP Apollo workstations running Unix, Pentica 68HC11 emulator, HP 4957A protocol analyzer, HP 3551A transmission test set, diagnostic tools for troubleshooting radio dispatch consoles, C, Pascal & 68HC11 assembler. Serve as team leader for providing technical, project & scheduling to other engineers. Provide technical leadership to in-house & field organizations concerning APCO-25 compatible system architecture & infrastructure signaling, & radio service software for dispatch, fixed & subscriber equipment configuration. Perform a principal role in process improvement activities in both group & individual tasks. Master's degree in Electrical Engineering or Computer Science required. Three years of experience also required in job offered or as Software Engineer &/or Installation Engineer &/or Electrical Engineering Consultant or any combination thereof. Experience must have included two years in development of real-time software for two way radio dispatch consoles using the Hatley & Pirbhai Structured System Specification & Design Method. Experience must also have included APCO-25 compatible feature development involving link control services, embedded & supplementary data functions, ■ narrowband land-mobile data communications protocol, & block protocols for synchronous & asynchronous computer communications; development & testing using HP Apollo Workstations running Unix or Aegis, Pentica 68HC11 emulator, HP 4975A protocol analyzer, HP 3551A transmission test set, diagnostic tools for troubleshooting radio dispatch consoles; C, Pascal & 68HC11 assembler programming languages; working on all phases of the software development process; & performing process improvement activities. Experience must also have included 1 year in connection, configuration & operation of APCO-25 compatible two way radio systems including dispatch, fixed ■ subscriber equipment; authoring effort quotes for software development projects; & interacting with in-house & field organizations. 40 hours, 8:30am to 5:00pm, $45,400/year. Must have proof of legal authority to work permanently in U.S. Send 2 copies of resume to Illinois Department of Employment Security, 401 South State Street - 3 South, Chicago, Illinois 60605, Attention: Dennis Jones, Reference #V-IL 12253-0. No calls. An employer paid ad.

PROFESSIONAL CONSULTING SERVICES

ADVERTISING RATES

12 insertions–$4200

1 insertion–$350

50% discount to IEEE members on three or more insertions.
If you are an IEEE member, please enclose your membership number with the order.

Copy cannot exceed 1-inch in depth.

No product may be offered for sale.

Advertising restricted to professional engineering and consulting services.
No orders can be accepted by telephone, order and copy must be sent together.

For any further information and closing dates please contact Advertising Production, 908-562-6334

editorial offices: New York City 212-705-7555 San Francisco 415-328-7570 Washington, DC 202-544-3790

EDITORIAL CORRESPONDENCE. IEEE Spectrum, 345 East 47th St., New York, NY 10017, Attn: Editorial Dept. Responsibility for the substance of articles published rests upon the authors, not the IEEE or its members. Letters to the editor may be excerpted for publication.
REPRINT PERMISSION. Libraries: Articles may be photocopied for private use of patrons. A per-copy fee (indicated after the code appearing at the bottom of the first page of each article) must be paid to the Copyright Clearance Center, 29 Congress St., Salem, MA 01970. *Other copying or republication:* Contact: Business Manager, *IEEE Spectrum.*
ADVERTISING CORRESPONDENCE. IEEE Spectrum, 345 East 47th St., New York, NY 10017, Attention: Advertising Department, 212-705-7760. Also see Advertising Sales Offices listing on last page. The publisher reserves the right to reject any advertising.
COPYRIGHTS AND TRADEMARKS. IEEE Spectrum is a registered trademark owned by The Institute of Electrical and Electronics Engineers, Inc. At issue, EEs' tools & toys, EV watch, Faults & failures, Hardware Reviews, Innovations, Legal aspects, Managing technology, Newslog, Program notes, Reflections, Software Reviews, Speakout, Spectral lines, Spinoffs, Technically speaking, The engineer at large, Washington watch, and Whatever happened to? are trademarks of the IEEE.
GENERAL INQUIRIES: 1-800-678-IEEE; Corporate Office: 345 East 47th St., New York, NY 10017, 212-705-7900. Tel. Extensions: General Manager 7910.

Operations Center: Box 1331, 445 Hoes Lane, Piscataway, NJ 08855, 908-981-0060. Tel. Extensions: acting General Manager 5311, Educational Activities 5485, Membership Services U.S. 1-800-678-IEEE Non U.S. 1-900-981-0060, Ombudsman 6360, Corporate Communications 6822, Regional Activities 5501, Section Services 5515, Technical Activities 3900.

IEEE U.S.A. Office: 1828 L Street N.W., Suite 1202, Wahington, DC 20036, 202-785-0017

coming in spectrum

Decontaminating the older nuclear power plant

As aging nuclear plants grow "hotter," the work of servicing them increases. At the same time, employees who perform the servicing must keep their total annual exposure to radiation below certain levels. Making matters worse for electric utilities is a potential dearth of these skilled workers, a shortage that could materialize in the near future.

Looking at ways to reduce plant radiation, some utilities are decontaminating the full primary (reactor coolant) system. This article describes the first such effort—at Consolidated Edison Co.'s Indian Point 2 plant in New York State.

Pace-setter Greatbatch

Still hard at work in upstate New York is Wilson Greatbatch, the inventor of the world's first medical device to be successfully implanted in the human body: the pacemaker for ailing hearts. Since the 1950s, he has developed inventions that have resulted in 130 patents, ranging from batteries to his latest endeavor, AIDS research.

Some novel uses of remote sensing

While remote sensing from satellites and aircraft is a well-known means of agricultural, marine, and climatic monitoring, its use for some very specialized purposes has attracted less publicity. This report surveys some of these unusual uses, among them the monitoring of natural disasters and their effects (such as the eruptions of volcanos Pinatubo and Mount St. Helens), the interdiction of illegal drug traffic, and the discovery of archaeological ruins.

The IEEE's home page on the Web

The IEEE now has a home page on the World Wide Web that can be reached using the Universal Resource Locator (URL): http://www.ieee.org. The page will guide users to information about member services (including the Job Data Bank), IEEE books and magazines, the Web pages of the IEEE's Technical Societies, and Regional and Student activities. It also has links to the IEEE's Standards Process Automation system, the text of stories published in *The Institute* (the news supplement to *IEEE Spectrum*), and a host of other IEEE products, services, directories, and organizations.

advertising sales office

345 East 47th Street, New York, N. Y. 10017

Michael Triunfo	Advertising Manager	212-705-7312
Dawn Becker	Mid-Atlantic Manager	212-705-7311
Eric Sonntag	Sales Promotion Manager	212-705-7017
Theresa Fitzpatrick	Assoc. Promotion Manager	212-705-7579
Martin Barbieri	Advertising Production Manager	908-562-6334

New Jersey–Alan Pearce, National Consumer Advertising Manager 368 Essex Street, Millburn, NJ, 07041 201-467-8121

Boston, MA–Doug Long, 46 Main St., P.O. Box 2780, Orleans, 02653 508-255-4014

Chicago, IL–Ralph Bergen, One Northfield Plaza, Suite 300, Northfield, 60093 708-446-1444

San Francisco, CA–Denis F. Duffy, 3755 Balboa Street, Suite 201, 94121 415-386-5202

Los Angeles, CA–Lynne Andrew Evans, 5757 West Century Boulevard, #700, 90045 310-649-3800

Atlanta, GA–H. Michael Coleman, C. William Bentz III, 4651 Roswell Road N.E., Suite #F503, 30342 404-256-3800

Denver, CO–David B. Schissler, 32570 Aspen Meadow Drive, Evergreen, 80439 303-670-3749

Dallas, TX–Matt Kincaid, Eric Kincaid, 9794 Forest Lane, Suite 634, 75243 214-553-9896

Tokyo, Japan–German Tajiri, IMI Corp., Saito Lend Bldg., 13-5, Ginza 3-chome, Chuo-ku, Tokyo 104. (03) 3546-2231. TELEX: J23449 (IMI TOKYO)

Munich, Germany–Ric Bessford, Leopoldstr. 52, 80802 Munich 40, Germany, 49-89-39-00-55

Surrey, England–John F. Gold, 16 Woodside Road, Sutton, Surrey SMI 3SU, Tel/Fax: 44 (0)81 641 7717

Associate Publishers: William R. Saunders (Advertising); Murray Slovick (Editorial); Fran Zappulla (Operations)

Administrative Assistants: Nancy T. Hantman, Christine Demchak

advertisers index

Circle numbers on the Reader Service Card, opposite page 73, that correspond to the advertisers listed below. *Advertiser in North American edition. **Advertiser in North American Exact edition.

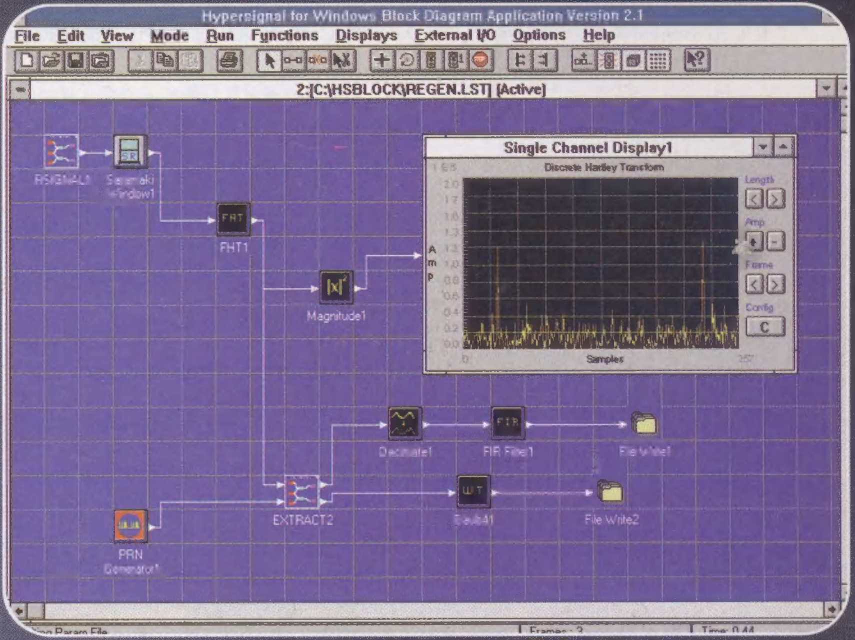

COREL DRAW! 5
The Best in Graphics and Publishing
CorelDRAW 5 combines the graphics power of CorelDRAW and the advanced publishing capabilities of Corel VENTURA 5 within an integrated user interface. With a revolutionary color management system, major performance gains and hundreds of improvements, CorelDRAW 5 retains the ease of use for which Corel is renowned. CorelDRAW 5 is the most exciting value-packed graphics and publishing software available.
With the new lenses in CorelDRAW 5 users can create incredible photographic effects such as transparency, magnify, grayscale, brighten, invert, heat maps, and more. Dynamic special effects can also be created using morphing, artistic filters, and masking. With 60 new additional fractal textures, CorelDRAW 5 allows for unlimited design variations.
Exciting New Filters
Amazing Morphing
Excellence
INCLUDES
CorelDRAW 5
Corel VENTURA 5
Corel PHOTO-PAINT 5
CorelCHART 5
CorelMOVE 5
CorelSHOW 5
PLUS
825 fonts
22,000 clipart images & symbols
100 high-resolution photos
CorelDRAW 5—"the best has gotten better!"
InfoWorld, August 1994-USA
"OUTSTANDING! CorelDRAW 5 really is the best graphics package ever!"
PC Answers, June 1994-U.K.
Versatile Charting
World CD-ROM Drive Shipments
Millions of Units
22
15
9
93
94
95
96
Power Publishing
COREL
1-613-728-3733
Corel Product Tour
A Corel representative is coming to your area to demonstrate our latest products. For details on how you can attend one of these FREE presentations and receive the complete US/Canada tour of cities, please call 1-613-728-0826 ext. 3080 and ask for Document # 1095 to be faxed. Demonstrations: Boston-Jan. 30; New York-Jan. 31; Philadelphia-Feb. 1; Baltimore- Feb. 2; Washington-Feb. 3; Dallas- Feb. 6.
CD-ROM version
$449.98*
* US$ plus applicable taxes.
Call for the location of the Egghead Software store nearest you. To order directly from our Eggspress Ordering Service, please call 1-800-EGGHEAD.
EGGHEAD SOFTWARE
North America's Software Eggsperts.
Hearing and Speech Impaired customers can reach us by calling 1-800-949-3447 TDD.
Eggspress Ordering
1-800-EGGHEAD
Call Direct
Enter the $2,000,000 World Design Contest and win! (September to March) To receive a faxed copy of the contest rules and an entry form please call: 1-613-728-0826 ext. 3080, Document # 1004. To leave a message please call: 1-613-728-0826 ext. 81609.
Circle No. 1
KUR-0085

Hypersignal® for Windows™

Comprehensive Visual Design Environment

Features

- Open software architecture
- **Hierarchical** Design
- Simulation at executable (not interpretive) speed
- **Industry Standard** Real-time DSP Board Support
- User Controls for custom dials, knobs, meters, etc.
- **C source code** generation
- Support for many different DSP chips (fixed and floating point)
- Automated block generation for user developed blocks
- Run-time support for user-developed applications
- New Advanced Transmission library for specialized communications projects
- Many new functions and transforms, including **Wavelets**

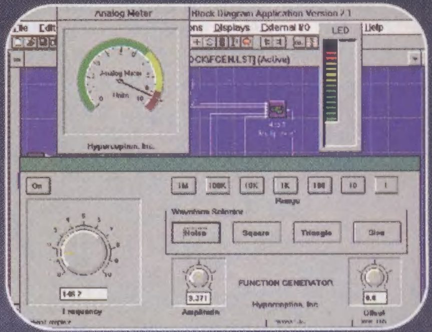


Comprehensive Simulation Environment

Hypersignal's open software architecture allows virtually limitless simulation/modeling to be performed for proof of concept designs, saving valuable engineering mantime.

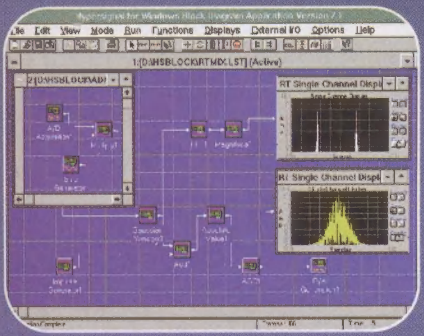
Applications

- **Visually Programmed** DSP Algorithm Development
- Rapid **Prototyping** of products and systems
- Virtual Instrumentation and Data Acquisition projects
- Many types of **Simulation** and **Systems Modeling**
- **Real-time DSP** and related Engineering Efforts
- Many other Research and Development projects



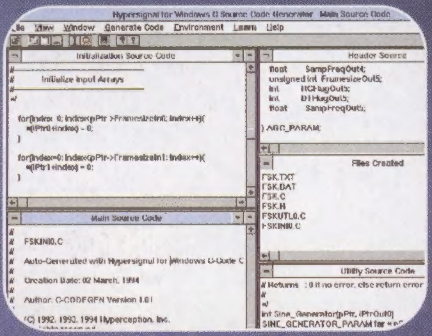
New User Control Interface

New User Controls allow for a greater variety of custom interface for both simulations and real-time projects.



Real-time DSP Board Support

Real-time DSP support using device independent DSP Board Drivers under Windows. This real-time graphical software language allows quick development of projects.



Automated C Source Code Generation

ANSI C source code generation from visually designed algorithms reduces design time for real-time projects through DSP C cross compilers, and allows portability to other c native platforms.

*For additional information, new **free** VideoTape Demo and DSP Sourcebook, contact:*

Hyperception, Inc.
9550 Skillman LB 125
Dallas, TX 75243

Phone (214) 343-8525 * Fax (214) 343-2457
BBS (214) 343-4108
for E-Mail information on Internet:
info@hyperception.com

Hyperception 10th Anniversary ***The Leader in DSP***

International Distributors

Circle No. 8

AUSTRALIA - Electro-Optics Pty. Ltd., phone: (02) 654-1873, fax: (02) 654-1539 * BELGIUM - Eurodis-Inelco, phone:(02) 244-2924, fax:(02) 216 4606 * DENMARK - Assentoft Electronics, phone:(86) 16-29-26, fax:(86) 16-20-12 * FINLAND - Farnell Electronic Services, phone: (90) 739-100, fax:(90) 712-414 * INDIA - Dynalog MicroSystems Pvt. Ltd., phone: (22) 5170514, fax: (22) 5171979 * JAPAN - Sumisho Electronics, phone:(03) 5228-8693, fax: (03) 5228-5621 * KOREA - Seoil Enterprise, phone: (02) 921-4127, fax: (02) 921-6437 * NETHERLANDS - Transfer EDS, phone:(053) 330338, fax:(053) 340336 * SINGAPORE - Neurotech PTE Ltd., phone +65 334-7080, fax: +65 336-7304 * SOUTH AFRICA - Technology Marketing Solutions, phone: (011) 882-6837, fax:(011) 640-3504 * TAIWAN - Exartech International, phone:(02) 977-6828, fax:(02) 977-6829 * U.K., IRELAND - Loughborough Sound Images, Ltd., phone: (0509) 231843, fax: (0509) 262433